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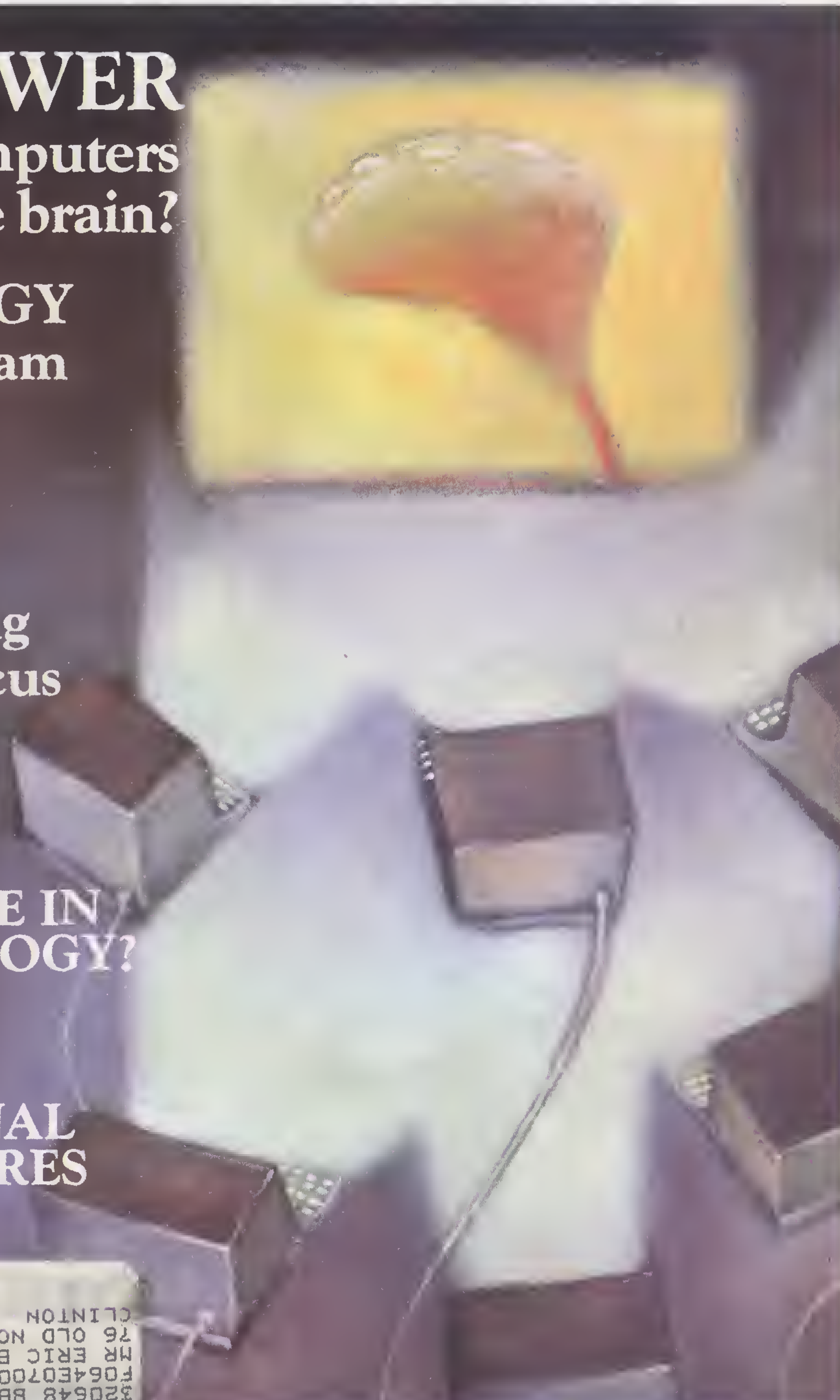

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The birth of a new generation.

A new coal gasification complex opened April of this year in Kingsport, Tennessee, making Kodak's Eastman Chemicals Division the first manufacturer in the United States to use modern coal conversion technology to produce industrial chemicals commercially from coal.

This method of manufacturing a new generation of chemicals saves us the equivalent of one million barrels of oil annually. A fact that makes us pleased. And just a little proud.

Using nearby Appalachian coal mines as a ready source of supply, the new plant can gasify about 900 tons of coal a day. That amounts to annual production of around 500 million pounds of acetic anhydride—a chemical needed to produce cellulose acetate, used in the manufacture of photographic film base, fibers, plastics and other products. Conventional technology, which uses ethylene produced from petrochemical feedstocks as the raw material, would consume the equivalent of a million barrels of oil to achieve the same results.

While some of the syngas processes were developed by others and licensed to Eastman Chemicals Division, new technological breakthroughs developed by us made the venture work.

Our innovations include: an energy-efficient method for producing refined methyl acetate, and a new process and catalyst system to produce acetic anhydride.

These achievements in chemical engineering and technology are steps in the right direction. Not only for ourselves (as coal gasification appears to be more economical), but for our country, too. We're now one step closer to independence from foreign oil.

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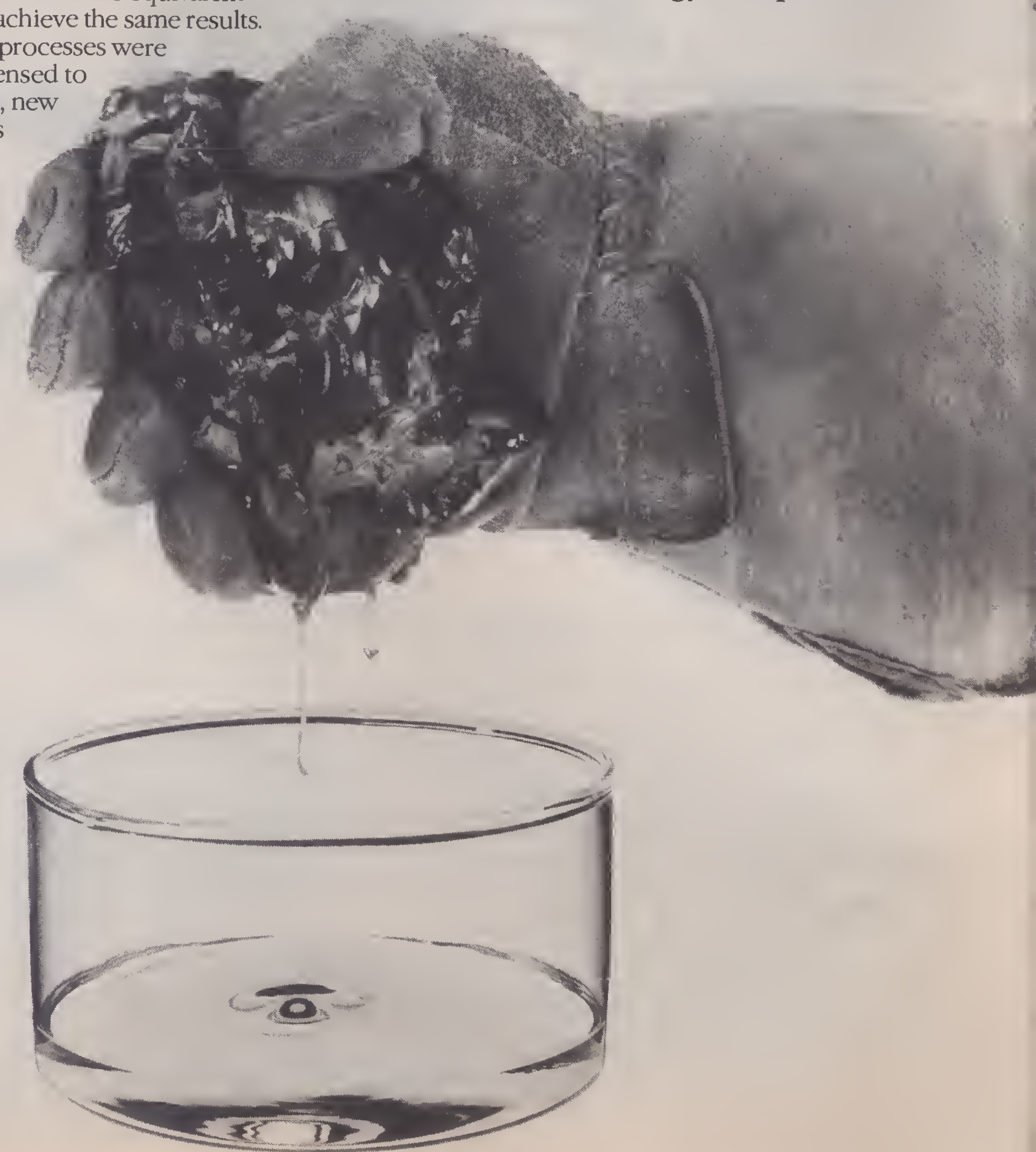

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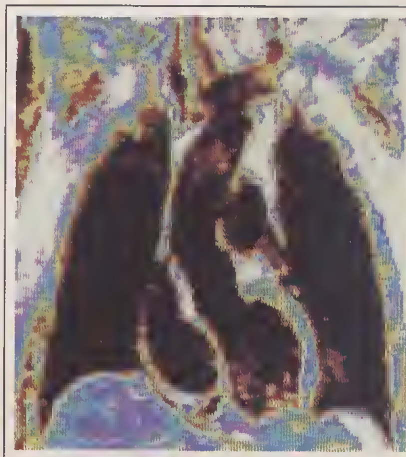

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Computers studying an EEG map dramatize the potential for designing machines that emulate the brain. (Illustration by Matt Mahurin)

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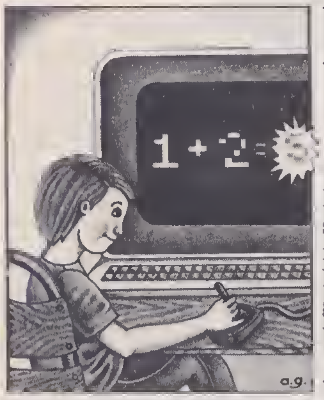
OPINION



ANNIE GUSMAN

Needed: new ideas for the schoolroom

Education continues to focus on stuffing students with facts. Yet it is clear that in a future technology-based society there will be a much greater need for resourceful people who can adapt to rapid change.

Because of growing concern about the quality of education, many communities have pushed their schools to "get back to basics." Although there is a need to do a better job of teaching basic skills, this movement will not do enough to prepare youngsters for tomorrow's world. In fact, since teaching these skills almost always entails rote methods, it will likely hinder rather than help develop the initiative and creative abilities that will be essential for success in the future.

One step these communities usually make toward innovative education involves personal computers. Parents *do* recognize the growing importance of computers in our daily lives. Some vendors, seeing the marketing potential in introducing kids to their systems, have been generous with equipment. Unfortunately, the computers are often not used innovatively and are usually confined to drill-and-practice programs based on rote learning.

The computer systems going into thousands of schools have the potential for a great variety of rich educational fare, stimulating a student to learn, use initiative, and apply creativity. The great success of computer games has demonstrated the degree to which attention can be focused. Yet most educational software falls far short of this potential.

Lacking good software, teachers struggle to get more value from the systems by helping students learn programming. But this is only a start. Without some challenging goals in the context of enlightened educational reforms, progress will be limited. Of course, there will always be a few very bright, self-motivated kids who move far and fast on their own, but it is the majority of students, not just the exceptional ones, who must be prepared to meet the challenges of the future.

New kinds of courses should also be developed. Simon Ramo, retired vice-chairman of TRW, proposes a high school course in which students choose a major problem involving technology, such as smog in Los Angeles or water resources in Phoenix. They would have to define the problem, propose alternate solutions, and then evaluate the potential and implications of each solution. They would thus be forced to develop data and to do some analysis—on which particulates are harmful and why, for example—which would show the students the value of technical knowledge and the need for sophisticated tools.

Educators face a tough task in transforming education. They need better support and understanding from their communities. And they need assistance from the high technology community, which itself could be much more imaginative in helping to develop innovative uses for its products.

Robert Haavind

Robert Haavind

high Technology

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Long Beach, Cal.

Nondestructive testing

"Uncovering hidden flaws" (Feb. 1984, p. 49) did a fine job of focusing on the classic use of nondestructive testing technology. We at Southwest Research Institute are working with new applications of NDT—productivity enhancement and component life management. These systems are being used to extend the life of components in operating plants beyond their original design life, to anticipate and schedule repair at regular intervals, and to increase produc-

(massive) satellites to higher orbits by dropping expendables into lower ones.

Neither suggestion is feasible. As to the power source, the induction of current in a conductor moving through a magnetic field is associated with a force resisting that motion. This scheme simply converts orbital energy directly into electrical energy. For a 100,000-kg spacecraft orbiting at 7500 m/sec, generating 100 kW decreases the orbital energy by about 0.25% after one day. At this rate, the scheme could be used on short missions tolerating orbital instability but not as a primary power source for permanent space stations.

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Bill Gunston
High Beach, England

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LETTERS

More bureaucracy?

I share the concern of the Opinion "Quicker solutions for national problems" (May 1984, p. 2) that our cumbersome government is ill prepared to study and resolve issues of national importance that involve technology. But the proposed public/private advisory councils, though excellent forums for generating innovative ideas, would do little to expedite action on these ideas.

First, government action in executing the programs would remain contingent upon the federal budget. Therefore all proposals would still have to run through the congressional mill, where they would be exposed to the special-interest lobbies.

And if the council implements its own programs, what would prevent it from itself becoming an inflexible bureaucracy, subject to the same laws and civil service rules that now hamper government agencies?

Finally, there is no guarantee that council members themselves would not develop constituencies much like special-interest lobbies in Congress. Indeed, lobbyists might target council members just as they now target members of Congress.

What is needed instead is a greater awareness of scientific and technological issues among members of the public. This technological literacy, translated through the voting booth into a Congress and President who are well aware of technological issues and willing to provide strong leadership, remains the best hope for intelligent public-sector responses to the increasingly difficult issues of our day.

Michael Shimazu
Boston, Mass.

The May Opinion vilifies bureaucracy while promoting yet another government department. In fact, high technology is leading us away from federal regulation; setting up a Department of Domestic Affairs would only shackle technology. We do not need advisory groups focusing on change. We need individual and group talents directed by the free market. Freedom to meet the challenge of change, not rampant bureaucracy, is what created the U.S.

Vance L. Shutes, Mfg. Coordinator
McDonnell Douglas
Long Beach, Cal.

Nondestructive testing

"Uncovering hidden flaws" (Feb. 1984, p. 49) did a fine job of focusing on the classic use of nondestructive testing technology. We at Southwest Research Institute are working with new applications of NDT—productivity enhancement and component life management. These systems are being used to extend the life of components in operating plants beyond their original design life, to anticipate and schedule repair at regular intervals, and to increase productivity in manufacturing industries by reducing the number of rejected components (at final inspection) to near zero. Our experience in these areas includes steam turbine rotors, jet engine disks, and metal cutting.

While conventional nondestructive testing simply looks for flaws, the key to our approach is to determine whether a flaw is harmful. Therefore equipment with certain flaws may remain in service, instead of being automatically replaced, because we now know that some flaws will not necessarily cause failure. Or, when we find defects that may cause failure, we can predict how long the machine can be safely operated before the defect becomes critical.

James E. Doherty, Director
Nondestructive Evaluation Research
Southwest Research Institute
San Antonio, Tex.

Supercritical water

In your thorough article "Supercritical fluids" (June 1984, p. 75), you briefly discuss our research using supercritical water in coal conversion. You cited me as saying that the use of conventional organic supercritical media suffers from problems with high pressures and corrosion. Actually, it is water, not organic media, that can present problems with pressures and corrosion.

However, the somewhat extreme conditions necessary for conversions in water may not be necessary. Under the proper circumstances, hydrothermal rather than strictly supercritical water could be very effective in bringing about the reductive degradation required for coal conversion.

David S. Ross, Manager
Fuel Chemistry Program
SRI International
Menlo Park, Cal.

Tethered satellites

In "Tethered satellites set for takeoff" (May 1984, p. 26), you mention supplying the "primary power needs of future space stations" with conductive tethers between satellites passing through the earth's magnetic field. Tethers are also proposed to boost (massive) satellites to higher orbits by dropping expendables into lower ones.

Neither suggestion is feasible. As to the power source, the induction of current in a conductor moving through a magnetic field is associated with a force resisting that motion. This scheme simply converts orbital energy directly into electrical energy. For a 100,000-kg spacecraft orbiting at 7500 m/sec, generating 100 kW decreases the orbital energy by about 0.25% after one day. At this rate, the scheme could be used on short missions tolerating orbital instability but not as a primary power source for permanent space stations.

Regarding the orbital boost concept, this makes sense only when the mass ratio of booster to payload is much greater than unity so that altitude gain is substantial and cable weight insignificant.

Ross R. Allen
Ramona, Cal.

It is incorrect to say "a single space vehicle in orbit around the earth is in equilibrium." Newton's first law for "balanced forces" states that a body will go in a straight line if in uniform motion. So your satellite will go off tangentially into space if your conditions are true. The orbiting body is actually under centripetal acceleration, which is gravity, and never subject to centripetal forces.

Also the wire cutting the magnetic field generates only a potential difference end to end. If you close the circuit to cause current, you will get nothing because the second wire generates the same potential difference, vitiating the current generator.

R.W. Long
Moore Haven, Fla.

Editor's note: Reader Allen is correct that by generating electricity the tethered satellite would lose altitude. Orbital energy can be restored by burning a small amount of fuel. To conserve fuel, solar cells mounted on the satellite could feed a reverse current into the tether; this current would provide altitude-boosting thrust as it cut field lines (a generator run backwards is a motor).

Allen's restrictions on the orbital boost concept are easily met, NASA says. The launching platform (e.g., a space station) will ordinarily be much more massive than the tethered satellite.

Reader Long is correct regarding centripetal vs. centrifugal acceleration.

He is also correct that a second wire to complete the circuit would yield zero net current. However, no return wire is needed; the ionosphere provides a highly conductive path to close the circuit. Since the ionospheric current remains fixed relative to the earth's magnetic field, no countervoltage is induced.

Tornado defended

The Tornado airplane is not "a technical, and perhaps financial, disaster . . . that does nothing particularly well" ("Superfighters," April 1984, p. 36). It is primarily a long-range all-weather interdiction aircraft. The 2000 pilots and navigators who today fly it will tell you that they know of no other aircraft—in the West at least—that can approach its excellence in any aspect of its mission capability, particularly its radius, fuel burn, radar signature, low-level terrain maneuvering and speed, navigation accuracy, systems redundancy, versatility, and smooth ride.

Bill Gunston
High Beach, England

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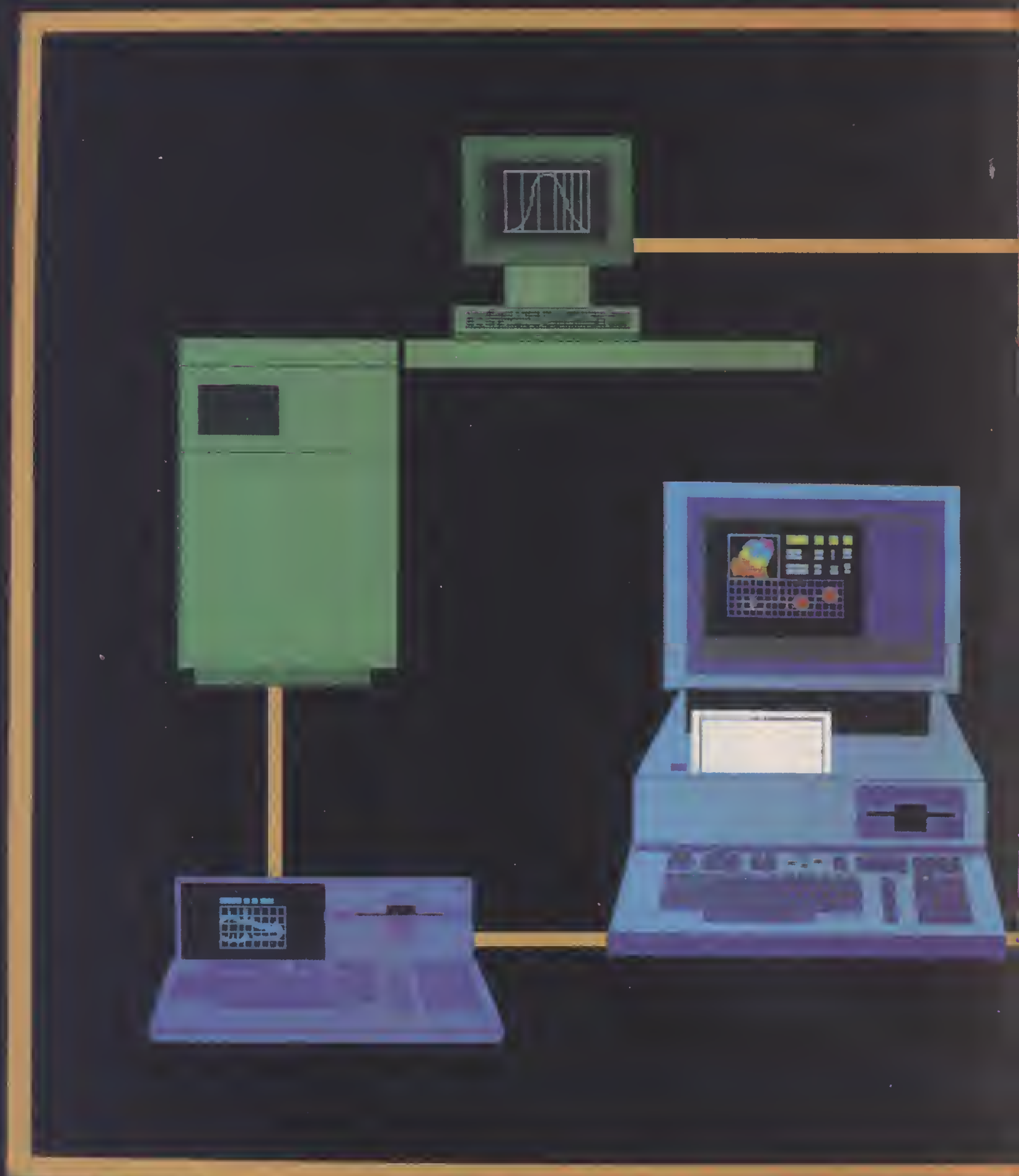

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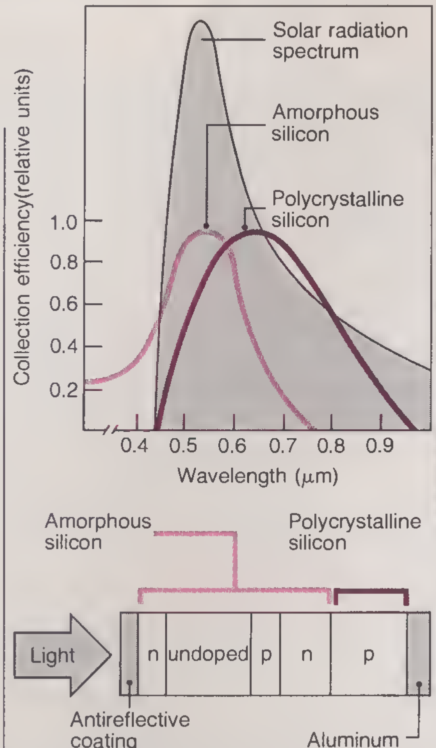


◀ *Osaka's tandem solar cell*

Infrared sensor shows where the fish are

Where warm and cold ocean currents collide, a kind of ocean "wall" forms. Because cold currents are rich in plankton, such a front attracts schools of fish. However, these fronts are not readily identified from the ocean surface. An infrared sensor developed by Fujitsu makes it easier to spot them. The new sensor will be aboard Japan's first marine observation satellite, the MOS-1, to be launched in 1986. The visible and thermal infrared radiometer (VTIR) will monitor infrared waves emitted by the ocean surface. These data can be used to make a thermal map of the ocean surface, showing ocean fronts and other features, thus helping fishermen.

The VTIR detects infrared with a highly sensitive semiconductor element made of a crystallized compound of mercury, cadmium, and tellurium. By varying the amounts of mercury and cadmium in the compound, the semiconductor can be "calibrated" to detect infrared across the band from 1.5 to 20 microns.

Efficiency rises for solar cells

Advances in efficiencies for solar cells made of crystalline silicon (19.1%) and a stacked junction of amorphous/polycrystalline silicon (12.5%) promise wider use for these devices. A group at the Univ. of New South Wales in Australia found that adding a semiconductor p-n junction to a metal-insulator-semiconductor (MIS) device increased efficiency beyond that for either structure alone. Other techniques, including double antireflective coatings and junction passivation, helped boost voltage output and cut recombination losses, so that 19.1% efficiency was reached for a 2 × 2-cm device. The Australians expect to hit 20% efficiency by the end of the year, according to team leader Martin Green. He predicts crystalline silicon cells could reach 23% in five years.

An Osaka University group built a tandem cell that combines amorphous (disordered, or glassy) silicon with polycrystalline silicon, achieving 12.5% efficiency (see diagram). Sunlight passes through the thin films of the 0.44-cm² tandem cell, and, since each material absorbs energy within a different portion of the solar spectrum, more complete conversion of the incident energy is achieved. These materials would be suited to low-cost commercial processes, according to Yoshihiro Hamakawa, leader of the Osaka U. group.

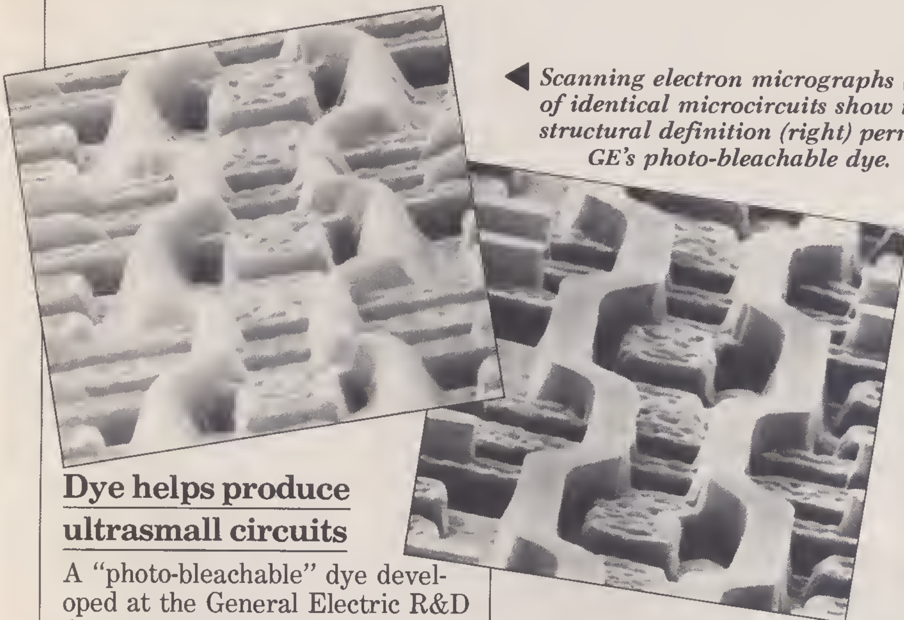
Chemical method improves drug separations

A simple and sensitive analytical tool may prove useful in drug research, treatment, and manufacture. Developed by chemist William Pirkle at the Univ. of Illinois (Urbana), the process—high-performance liquid chromatography on chiral stationary phases, or HPLC-CSP—separates optical isomers (hard-to-isolate chemicals that exist in two forms, mirror images with different properties). The FDA is now adapting the method to drug studies.

A tiny sample is passed through a column containing a chemical (the stationary phase) that is itself optically active. One optical form of the drug being tested temporarily attaches to the stationary phase; the other form passes through the column for collection and analysis.

Of the 20 most prescribed drugs, 12 exist in two optical forms (a property called chirality), denoted right- and left-handed. The left-handed form of the hypertension drug propranolol, for example, is 100 times more potent than the right-handed form. And only one form of the drug thalidomide caused the birth defects that became evident in the early 1960s. Many mixed solutions of such molecules can be analyzed by passing polarized light through them. A right-handed molecule rotates the beam in one direction, while the left-handed form rotates the beam in the opposite direction. But this method is not always reliable, and it requires relatively large samples.

Because HPLC-CSP uses very small samples, it may be especially helpful in monitoring drug therapies, according to FDA chemist Thomas Doyle. The process is being scaled up for drug producers, enabling them to isolate the desired form during production.



Scanning electron micrographs (8000×) of identical microcircuits show the improved structural definition (right) permitted by GE's photo-bleachable dye.

Dye helps produce ultrasmall circuits

A "photo-bleachable" dye developed at the General Electric R&D Center (Schenectady, N.Y.) permits existing semiconductor process equipment to halve the circuit linewidths it can currently produce. The dye also helps produce chips with more precisely defined microstructures, resulting in improved operation. Using the dye, GE has fabricated experimental microcircuits with linewidths of 0.4 microns and will begin producing 1.2-micron commercial chips later this year. Most commercial chips now have 2- to 4-micron linewidths.

In chip production, various types of optical systems project the image of a circuit pattern (contained on a photo negative-like "mask") onto a semiconductor coated with a light-sensitive photoresist. As circuit sizes shrink, the resolution capabilities of the projection lenses become strained, causing fuzzy images and poor circuit definition. The GE dye, applied to the wafer prior to exposures, is able to redefine these blurry images by changing from opaque to transparent at locations struck by high-intensity light. Because light intensity is greatest at the center of the blurred projection lines, the bleached areas serve as windows that resharpen the definition of the light passing through to the photoresist. The result is improved definition between areas with circuitry (unlighted) and areas without circuitry (lighted).

Program spots bugs in milling routines

A computer program developed by Sandia National Laboratories (Albuquerque, N.M.) can prevent damage to machine tools and metal parts by subjecting newly devised automated machining routines to "dry run" simulations. The program, called Multax-Plot, provides visual verification that numerical instructions for machining a complex part are correct and workable before any material is actually cut. Until now, detecting bugs ahead of time has been difficult because the instructions for a part may require over 5000 lines of computer code.

Multax-Plot displays are shown in perspective on a color graphics terminal. The user can view any point of a part from any angle and can scale up small areas. The program can draw the entire path of the cutter or any portion of it. An "inspect" mode allows all motions and command data to be examined one step at a time. The cutter path is normally shown as a single line in 3-D space, but the cutting diameter at a given point can also be displayed.

Colors are used to contrast feed rates, cutter outlines, machine limits, and reference axes. Future versions of the program will be able to show the position of the tool in relation to the part; the display will include the tool head, the table orientation, the tool axis, and other features.

Computerized scanner foils counterfeiters

Product counterfeiting is a growing problem for many manufacturers—more than $20 billion worth of counterfeit products were confiscated in 1981. Fakes are often so convincing that they cannot be detected by visual inspection alone. Now a computerized scanning system, developed by Light Signatures (Los Angeles), promises to help stem the tide of fraudulent goods.

An intense beam of light is passed through an existing product label or document. Then a computer measures light intensity at random points along the illuminated spot and converts the data into a code that is printed on the label. Because the random fiber patterns in leather or paper are as individual as fingerprints, each label is given a different identification number. The system, which can scan and imprint 100,000 labels per hour, employs random algorithms that are changed frequently to thwart electronic intruders.

Once the products have been distributed to retail outlets, customers or manufacturer representatives mail the labels to the Light Signatures facility. There the labels are passed through a scanner that matches the fiber pattern with the identification number in about four seconds, enabling manufacturers to verify their authenticity. The system can protect clothing, records, jewelry, accessories, credit cards, ID cards, documents, works of art, and paper currency.

Leadership is the best defense

by Roland W. Schmitt
Senior Vice-President, Corporate Research and Development
General Electric Company

The United States may have superior technology, but too often we find that the Soviet Union has superior weapons. We are good at generating new technology but often slow to apply it. The Soviets, meanwhile, are good at extracting technology from us and deploying it rapidly.

To correct this situation, we must do two things: prevent them from getting our technology and speed up our own deployments. But that is like saying that to win in sports you must score a lot of points and prevent your opponent from scoring. There is more to it.

It makes a big difference, for example, whether you are playing football or basketball. The balance between offense and defense is vastly different in the two. In basketball, unlike football, you cannot indefinitely strengthen the defense without weakening the offense. The same holds true for our technological battle with the Soviets. An obsession with a defensive strategy—with preventing leakage of our technology—will cripple our offense, our ability to remain the leader in generating new technology.

Nevertheless, a change in the balance between a leadership strategy and a protective strategy—with an emphasis on the latter—is currently being proposed. In the past, we essentially put a fence of export restrictions around the Soviet Union and Eastern Bloc countries to keep technology out. The new strategy would put the fence around the United States to try to keep technology in.

Such a change has vast implications, not only for our national security but for our international economic competitiveness as well. Open communication of innovative ideas has helped keep us in the forefront in science and technology. We must therefore look very closely at the rationale behind the new strategy. There are four key issues: dual use, or the extent to which the same technology can be used in both military and civilian applications; military criticality; foreign availability; and effectiveness of technology transfer.

The dual-use issue is as old as technology itself: as old as the swords and spears that the prophet Isaiah proposed pounding into plowshares and pruning hooks; as old as the telescope that a couple of lens grinders in Holland invented as a means to spy on their enemies but that Galileo turned into something very different.

It wasn't so long after Galileo's day that military telescopes and those used by astronomers began to diverge. Generally speaking, dual use diminishes as you go from fundamental science toward final application.

Consider the example of very large-scale integrated (VLSI) circuits. At the level of basic science, the things one has to learn about—such as diffusion constants, carrier mobilities and lifetimes, and hot electron effects—are clearly generic to all possible applications. Dual use is complete. The same goes for the next stage, engineering principles, in which steps such as ion implantation or photolithography are common to military and civilian technologies. Dual use also persists to a large extent in the fabrication processes for VLSI.

But by the time you reach the application stage, the chips used in military systems are likely to differ from the ones used in commercial products. Popular press reports to the contrary, it's unlikely that a chip from a video game could really serve as the critical part of a missile guidance system.

In the final stages of military deployment of technology, the Soviets have in many cases been faster than us, as I suggested earlier. And recently they have appeared to be improving further upstream—in the direction of engineering principles and fundamental science—giving rise to demands for more controls at the early stages.

I believe that these demands are misguided, however, and that they would cost us more in leadership than they would gain us in protection. Dual use is not sufficient reason to encumber technology development, particularly at the fundamental science and engineering stages. It is only in the areas from engineering prototypes downstream to specific applications that controls should be considered.

One particularly dangerous proposal would put new limits on research by foreign nationals. Ironically, such people perform a very high percentage of the research at American universities. A recent study by the National Research Council found that half of the U.S. engineering doctorates awarded in 1982 were received by foreign nationals and that 39% of those degrees went to people on temporary visas.

I can think of nothing that would do more damage to American leadership in science and technology than cutting ourselves off from this source. In fact, foreign nationals should be *encouraged* to participate in fundamental research in the U.S. Even in some of the more applied fields, the need for skilled people is so urgent that I believe the Departments of State, Defense, and Commerce should find ways to open the doors of engineering laboratories to foreign nationals who can be adequately screened.

This article is adapted from a recent presentation to the Meeting on Export Controls and Technology Policy at the National Academy of Sciences.

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HT 37-83

Military criticality must not be confused with military utility. A militarily critical technology gives a nation's armed forces a new capability that could change the military balance. By contrast, a militarily useful technology makes only an incremental improvement, by either upgrading performance or enabling a nation to produce more of the weapons it already possesses for less money or in less time.

The Department of Defense has compiled a 700-page "Militarily Critical Technologies List." Its name suggests that this distinction has been taken into account. But in fact, the list is a combination of militarily critical and militarily useful technologies.

As I see it, that list has two purposes. The first, which the present list fulfills admirably, is to alert the Department of Commerce to sensitive areas; the Department of Defense may then review proposed licenses for export of technical data to communist countries. Remember that all such export to those countries is already controlled. The full list simply makes control more effective by highlighting technology with military applications.

The list's other purpose is to control technology exports to noncommunist countries. In that regard, the present list is far too inclusive. It would put severe restrictions on sharing of many militarily useful technologies with those nations. This would hurt us both economically and technically. These two liabilities would, in my view, outweigh the benefits of the restrictions.

So we need a second version of the "Militarily Critical Technologies List"—one that includes only the technologies that its name implies. If a technology is found to be militarily useful but not critical, its export to noncommunist nations should not be subjected to the strictest controls.

The issue of foreign availability is really two questions: What does it actually mean, and what impact does it have? Foreign availability can be defined so narrowly that you find no such technology anywhere. The essential thing, however, is not carbon-copy availability but functional equivalence: Can the technology available overseas do the same job as the one available here?

Two computer memory chips, for example, might be deemed functionally equivalent if they both pack the same number of bits onto the same area of silicon with the same access time, even if they achieve this by totally different processes and design rules. The real question is whether the military function can be accomplished in an equivalent way by a different technology available from a source other than the United States.

This concept of functional equivalence has been written into proposals for updating the Export Administration Act, and I believe it belongs there. But we must also raise the question of impact. If a friendly nation already has a technology capability, we can gain more by including them within the fence than by shutting them out. Therefore I recommend that we permit general licenses on exports to friendly nations for technology that is available to them anyway, and that we use bilateral agreements to strengthen controls—to keep that technology from going beyond those countries to the Communist Bloc.

Suppose a technology meets all three criteria discussed so far—it has dual use, is militarily critical, and is not available overseas. Then there is one more issue to be considered in applying controls: effectiveness of technology transfer.

In the case of VLSI design and process technology, for example, we should be highly concerned about the Soviets' acquisition of know-how and equipment that pertain to photolithography systems, steppers, ion implanters, and computer-aided design terminals and computers. We should also put strict controls on such things as equipment design drawings. Once again, the fence must enclose other friendly nations, not the U.S. alone, because many of them are producing equipment as sophisticated as our own.

In considering the effectiveness of transfer methods, VLSI presents a special problem. Chips are so small that we must assume they will be stolen, even if classified. Thus an additional measure would be to make the chip immune to reverse engineering—to being taken apart layer by layer to find out how it was designed and made.

But having put such defenses in place, we will do ourselves no good by attempting to further restrict scientific and engineering communication. The free flow of such information helps us much more than it helps our adversaries. Excessive restrictions would buy us little protection in exchange for great damage to the creative process by which Western industrial nations have attained and maintained technological leadership. □

U.S. REVIVES SPACE NUCLEAR POWER

Orbiting reactors could fuel space stations, satellites, and laser weapons

A compact nuclear power plant is linked by a boom to an orbiting space station in this artist's conception. The reactor is the white-hot cylinder at the tip of the cone; the white ring behind it is a radiation shield. The red-hot panels make up the radiator, which discharges waste heat into space.

GE SPACE SYSTEMS DIV.

The nuclear industry may be in financial trouble on earth, but its future looks bright in space. After a hiatus of more than a decade, the United States is embarking on a new program to develop space nuclear reactors for a variety of military and civilian applications. On February 11, 1983, three U.S. government agencies—NASA, the Dept. of Energy (DOE), and the Defense Advanced Research Projects Agency (DARPA)—signed a Memorandum of Agreement to jointly manage a space-reactor R&D program known as SP-100. This effort has a near-term goal of developing a 100-kilowatt space reactor, and a longer-term objective of a multimegawatt space reactor. According to DARPA's William Wright, director of the SP-100 Program, between five and 10 of the lower-power reactors could be in orbit by the year 2000.

In fiscal year 1984, total funding for the 100-kilowatt reactor project was \$13.6 million; the official request for FY85 is \$16 million (\$8 million for DARPA, \$4.1 million for DOE, and \$3.9 million for NASA). Recently the FY85 DARPA funding share was incorporated into the budget request for President Reagan's Strategic Defense Initiative, which calls for development of a nationwide antiballistic missile system based on lasers and particle beams in space. These futuristic "star wars" weapons would require many hundreds of megawatts of electric power, which might eventually be supplied by large space-based nuclear reactors.

Critics of the renewed effort to develop space reactors have raised concerns about safety, pointing to incidents in 1978 and 1983 when Soviet nuclear-powered satellites accidentally reentered the atmosphere and contaminated the environment with radioactive fission products. But SP-100 officials reply that safety is a major priority of current R&D efforts and that the risks can be reduced to acceptable levels.

by Jonathan B. Tucker

History. Space nuclear power is not a new idea. Throughout the 1950s and '60s, the United States developed nuclear systems for rocket propulsion and for generating electric power in space. Radioisotopic thermoelectric generators (RTGs), which produce electricity with heat from the decay of a radioactive isotope, have been widely used on satellites and deep space probes such as the Viking mission to Mars. Unlike RTGs, space reactors harness the energy released by a nuclear chain reaction and hence are capable of much higher power levels.

The use of fission reactors in space was pioneered by the U.S. Systems for Nuclear Auxiliary Power (SNAP) program, which began in 1955. Although six reactors were developed, only one was actually flight-tested: The SNAP-10A reactor was launched into orbit on April 3, 1965, and generated 500 watts of continuous power for an Agena spacecraft; it shut down after 43 days because an electronic circuit malfunctioned. The SNAP program was terminated in 1973 after the expenditure of several hundred million dollars because constraints on payload size kept electric-power needs in space limited to a few kilowatts. Today, however, the advent of the Space Shuttle has made it economically feasible to launch into orbit larger, more sophisticated spacecraft that consume high levels of electric power, arousing renewed interest in space reactors.

The Soviet Union has also been involved in space nuclear power since the 1960s. It has developed both RTGs and two types of fission reactors known as Romashka and Topaz, with estimated power outputs of 10–40 kilowatts. These reactors have been used to power Cosmos radar ocean-reconnaissance satellites (rorsats), which circle the earth in a low orbit of about 150 miles and monitor naval surface vessels. Ever since the accidental reentry of a Cosmos satellite in early 1983, however, no additional Soviet space reactors have been deployed.

The uses

Summary:

Even the smoothest voice is discontinuous, especially in conversation. Data communications has bursts of message and periods of silence, too. Even TV has some "bursty" traits. GTE scientists are isolating silences and inserting other messages into them. This permits voice and data to coexist on the same channel at the same apparent time. The development stems from parallel research in microelectronics, silence detection, speech, voice compression and signal processing.

Without basic change, or vast growth, telephone networks will be unable to cope with the anticipated traffic of the 1990's. The proliferation of personal computers and data terminals has already placed a strain on switching and transmission facilities. It has also placed demands on networks that are much different from the original voice-communications concept, in which average time of connection was three minutes.

Today, far shorter and far longer connections abound, more subscriber lines are in demand, and there are growing needs for enhanced services and faster switching.

Out of research dating from 1979, GTE has developed a switching system that promises not only to triple present transmission capacity but also to process calls 20 times faster. The system is called Burst Switching.

The nature of speech.

Our world is full of holes. Matter is mostly empty space. Conversation is mostly silence. But, even though speech is 2/3 silence interspersed with bursts of sound from 0.1 to 1.5 seconds long, if that speech goes over a telephone line, the line is locked up for the duration.

But, with Burst Switching, we can shoehorn other messages into the silences, automatically easing the pressure on transmission facilities. Theoretically, in fact, we triple transmission capacity.

VHSIC.

Through Very High-Speed Integrated Circuits (in which we are currently researching devices with submicron feature size), we are able to make and break telephone connections at increasingly high speeds. Voice lines need be dedicated only for the very brief duration of voice bursts. At other times, channels are available for other voice messages, or for data streams which are also "bursty" in nature. In addition, video, because of its built-in redundancy, can be considered to have bursts, too.

# of silence.

Message compression.

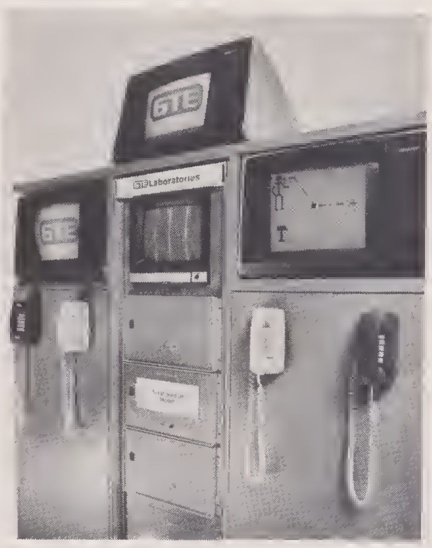
The capacity needed to transmit speech can be made even smaller if the information that must be sent to make it recognizable can be minimized. Our scientists have reduced the 64 kb/s signals to 16 kb/s while retaining high quality.

Thus, transmission-capacity requirement is reduced by a factor of four.

We are working, as well, on techniques for compressing video signals from 90 Mb/s to 64 kb/s. This will have special relevance for such activities as video conferencing.

So transmission capability grows and switching becomes faster—and we can now envision future telephone systems able to carry billions of simultaneous calls.

The box at the right lists some of the pertinent papers GTE people have published on Burst Switching and related subjects. For any of these, you are invited to write GTE Marketing Services Center, Department TPIIB, 70 Empire Drive, West Seneca, NY 14224.



Burst Switching experimental model.

Pertinent Papers.

Burst Switching—An Introduction, IEEE Communications Magazine, November 1983.

New Switching Concept Integrates Voice and Data Bursts, PROFILE, September 1983.

A PCM Frame Switching Concept Leading to Burst Switching Network Architecture, IEEE Communications Magazine, September 1983.

Application of the Burst Switching Technology to the Defense Communications System, Proceedings 1983 IEEE Military Communications Conference, MILCOM '83, Washington, D.C.

Performance Evaluation of a Distributed Burst-Switched Communications System, Proceedings Second Annual Phoenix Conference on Computers and Communications, March 1983.

A Complementary Speech Detection Algorithm, Proceedings of GLOBECOM '83, November 1983.

GTE

In Burst Switching, the roughly 65% silence in speech can be filled with data streams and other messages, effectively tripling transmission capacity.

Applications. Fission reactors are the technology of choice for generating large amounts of electricity in space. Alternative sources are limited in power output and longevity: RTGs have an output of about 10 kW when used to operate a turbine, fuel cells can generate 15–20 kW but have a short lifetime, and solar photovoltaic arrays reach their practical limit at about 75 kW. Because solar arrays for generating high power levels must be very large, they create drag against the outer fringes of the atmosphere in low earth orbit, requiring the expenditure of large amounts of rocket fuel to keep the spacecraft aloft. Moreover, solar panels are degraded by intense radiation environments such as the Van Allen Belts around the earth, and they perform poorly in deep space (beyond Mars) because of the low intensity of sunlight.

NASA is therefore interested in space reactors for future missions in which solar panel/battery systems are not practical. Potential applications include large space platforms in geosynchronous orbit, spacecraft operating in intense radiation environments, nuclear electric propulsion for deep space probes, long-term lunar and planetary bases, space industrial applications (such as crystal growing and containerless melting of glass for fiber optics), asteroid mining, and advanced manned space stations in low earth orbit. "The first space station will require about 75 kilowatts, which will be supplied with solar cells. But pretty soon it's going to need 200–300 kilowatts, and then they're going to have to consider a nuclear power plant," says Judith Ambrus, the SP-100 deputy program manager from NASA.

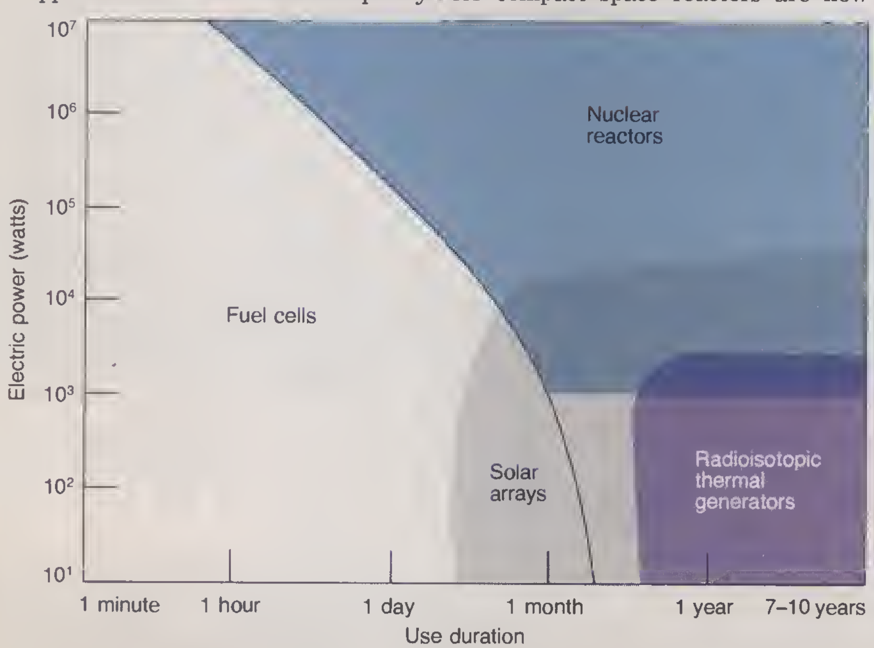
Emerging military missions in space will also require high levels of electric power. Upgraded military satellites are now being planned for command, control, communications, and intelligence (C^3I) applications, including jam-free communications with mobile ground stations, and space-based radars for air defense and ballistic missile tracking. In principle, compact, shielded reactor power sources could make military satellites tougher and more maneuverable and hence better able to survive an antisatellite (ASAT) attack than spacecraft equipped with bulky, fragile solar panels. (Although space reactors would radiate large amounts of waste heat, making them easy targets for homing infrared ASAT weapons, any operating satellite has a bright infrared signature when compared with the frigid background of space.) The primary military application of multimegawatt space reactors would be to power space-based beam weapons for ballistic missile defense.

Development. According to the working specifications for the 100-kW reactor, it should fit into a third of the Space Shuttle payload bay (20 × 15 feet), weigh under 3000 kilograms, and have an operating lifetime of at least seven years. Three alternative designs for compact space reactors are now under consideration. General Electric's Space Systems Div. (Valley Forge, Pa.) has proposed a reactor that can generate electricity either with a dynamic Stirling-cycle turbine or with a static conversion system in which thermoelectric devices are radiatively heated by a lithium-metal working fluid, flowing in vapor phase through heat pipes attached to the reactor. The second design, from GA Technologies (San Diego—formerly General Atomic), uses a thermionic conversion system in which a tungsten cladding over the nuclear fuel is heated by the chain reaction to about 2000° F; electrons boil off the metal and collect at an anode, producing electric current. The third design, submitted by Rockwell International's Energy Systems Group (Canoga Park, Cal.), is based on a three-piston Stirling engine. A decision on which design will proceed into ground-demonstration trials will be made by July 1985; a reactor prototype should be completed by the late 1980s, and flight testing from the Space Shuttle could begin by the mid-1990s.

No matter which design is chosen, the severe constraints on reactor mass and volume will require the use of high temperatures, creating materials challenges. Improvements will be needed in nuclear fuel composition, cladding materials and geometries, and structural materials for the reactor and conversion systems. Current research is focusing on high-strength, high-temperature refractory alloys such as niobium-zirconium. Extensive studies will be required on the fabrication and welding of these alloys, their long-term mechanical behavior under high temperatures and intense radiation, and chemical interactions among the various reactor materials—for example, uranium oxide fuel, refractory-alloy cladding, and liquid-metal coolant.

Multimegawatt space reactors will most likely require a different set of technologies. NASA-Lewis Research Center (Cleveland) is doing a classified study to identify viable reactor and energy-conversion concepts for multimegawatt systems and to estimate their physical size and mass, operational characteristics, and launch-vehicle requirements. A design concept will be selected by 1991.

Safety concerns. Space reactors will clearly have to possess strong and inherent safety features. Public concern over safety has been heightened by the fact that the U.S. and Soviet space nuclear programs have already experienced some serious accidents.



Analysis of applicability of different generating technologies to space missions of various electric-power requirements and orbital durations indicates that nuclear reactors are best for supplying high power levels over long periods.

LOS ALAMOS NATIONAL LABORATORY

Between 1961 and 1982, the United States launched 24 RTGs and one reactor, and the Soviets deployed three RTGs and 25 reactors, 70% on military missions, according to data from the Stockholm International Peace Research Institute. During this period, five accidents occurred, three of which resulted in the release of radioactive material into the environment:

- On April 21, 1964, a U.S. Navy Transit satellite was launched carrying a SNAP-9A RTG with a plutonium-238 power source. The spacecraft failed to attain orbit and burned up in the atmosphere over the Indian Ocean, reportedly releasing 17,000 curies of radioactivity. Roughly 95% eventually fell to earth, causing an estimated threefold increase in the global inventory of plutonium fallout.
- On January 24, 1978, a Soviet military ocean-surveillance satellite, Cosmos 954, accidentally reentered the earth's atmosphere and partially burned up, strewing large chunks of radioactive debris over parts of northern Canada. Had the reactor disintegrated over a populated area, the results would have been catastrophic.
- On February 7, 1983, another Soviet nuclear-powered surveillance satellite, Cosmos 1402, reentered the atmosphere over the South Pacific. This time the reactor was designed to burn up during reentry, but it still contaminated the environment with radioactive fission products.

Chastened by the international uproar that followed the Cosmos incidents, SP-100 officials are making a concerted effort to ensure that the next generation of space reactors will be safe. According to Gary Bennett, director of safety and nuclear operations in DOE's Office of Special Nuclear Projects, the reactor will be launched "cold": Nuclear fission will begin only after orbit has been attained. Thus the reactor will not contain any highly radioactive fission products at the time of launch.

Space reactors will also be designed so that if the rocket explodes or the mission is aborted shortly after launch, the nuclear material will be contained inside the reactor and will remain subcritical—incapable of sustaining a nuclear chain reaction. This requirement must hold even if the nuclear fuel is immersed in water (say, after jettison of the reactor into the ocean) or severely compressed by ground impact. One approach under study is to place a neutron-absorbing plug into the reactor core. The plug, which would "poison" the chain reaction, would be removed when the reactor had reached a safe orbit.

According to SP-100 director Wright, the U.S. does not intend to place nuclear-powered satellites in low earth orbit. "We expect that for virtually all applications, it will be acceptable to put the reactor into a 'nuclear-safe' orbit that should ensure that most of the fission products decay before the spacecraft reenters the atmosphere," he says. A nuclear-safe orbit has an altitude of about 500–600 miles, high enough so that atmospheric drag is minimal and the orbit decays very slowly over at least 300 years.

Because manned space stations will be deployed in low earth orbit, NASA is seeking a safe way to provide them with nuclear electric power. One idea is to place the reactor in a high, nuclear-safe orbit and transmit the power down to the space station by physical tether or microwave beam. Alternatively, the reactor in high orbit would split water to produce oxygen and hydrogen fuel, which would then be ferried down to the space station.

If all space reactors were deployed in nuclear-safe orbits, the major safety hazard would arise from a rocket-stage malfunction that prevented the reactor from reaching its intended altitude, causing it to enter an unstable orbit and eventually reenter the atmosphere. Two solutions to this problem are currently under study. One approach is to design the reactor so that it disassembles spontaneously and burns up fully in the upper atmosphere, dispersing the nuclear fuel as a fine dust over a large area so as to minimize the radiological hazard. The other approach is to allow the reactor to reenter intact, with a radio beacon on board so that it can be found quickly.

Despite SP-100 officials' intensive efforts to ensure the safety of space reactors, skepticism remains high among critics such as Robert M. Bowman, president of the Institute for Space and Security Studies (Potomac, Md.). He notes that reentry of the intact reactor could be hazardous if it hit the ground, and that reactor burn-up and dispersal of the uranium fuel would create a fallout hazard. Bowman has therefore urged that an environmental impact study be done to evaluate the potential risks of orbiting reactors before intensive work on nuclear-powered satellites gets underway. □

Jonathan B. Tucker is a senior editor of HIGH TECHNOLOGY.

ELECTRONIC MAIL SPARKS INTEREST

Proliferating micros plus promotional push boost messaging systems

After cycling in and out of business favor for close to 20 years, electronic mail is set to establish its presence once and for all. The technology, in its broadest sense, encompasses all types of electronic messaging, including facsimile transmissions, telexes, Mailgrams, and voice. In recent years, however, electronic mail has increasingly been associated with text messages transmitted between users of networked computers.

Such computer-based messaging systems (CBMSs) fall into three broad categories: services, software, and hybrids. The oldest are the services, available through timesharing vendors or value-added network companies (which augment public networks). Software systems, which include both applications packages and turnkey hardware/software solutions, have been commercially available for three years (although proprietary systems existed long before that). Hybrids, which mix electronic inputs with paper delivery options, are the newest alternative gaining attention.

Unlike the more traditional electronic messaging systems, the newer electronic mail technologies usually incorporate store-and-forward capabilities, analogous in a sense to paper-based mail services. The time a traditional postal service uses to process and forward messages may be considered storage. In electronic mail systems, sending messages takes microseconds, and the messages are stored on magnetic disks until the recipients choose to access them.

Electronic mail vendors hope to exploit two recent developments to secure a more stable niche for their products in the business world. One development is the proliferation of microcomputers in offices everywhere, thanks in part to the micro's ability to double as a terminal linked to a host computer. Micro users have begun to appreciate the ability to communicate with others via an electronic network. Such communication is one more software application helping to justify the cost of microcomputer hardware at many sites.

The other development likely to stimulate acceptance of electronic mail is the huge advertising campaign for MCI Mail. When the MCI Digital Information Service Co., a division of MCI Communications (Washington, D.C.), announced its electronic mail service late last year, it began a yearlong, $12 million advertising spending spree. Aside from touting MCI's proprietary system, this effort should help educate consumers about electronic mail concepts in general.

Most CBMSs are essentially database management systems. Here the "database" consists of messages, and "management" means coordination of storage and access. People authorized to use the system create messages on their terminals and send them to other network users. The computer's mail management program delivers the message to the appropriate disk storage slot ("mailbox") and also creates a pointer, which appears on the recipient's terminal screen, indicating that a message awaits.

Recipients can open only their personal mailboxes, using passwords issued when they first join the system. Each time the user signs onto the system with his password, the system notifies him whether messages await.

When senders post messages to multiple addresses, the computer stores just one copy, but creates a pointer for each recipient. This keeps mass storage requirements to a minimum. When a user requests the message, the system gives him access to the one copy stored in memory and allows him to read it. Should the reader wish to edit the message, most systems then make a copy to preserve the original's integrity.

Today, electronic mail technology can be cost-effective for virtually any communications requirement. A business letter costs $7.60 to dictate, transcribe, and mail, according to the Dartnell Institute of Business (Chicago), a firm that charts the expense of doing business. This doesn't include the costs associated with corporate mail departments that handle the letter on both the sender's and recipient's ends. Electronic messages can cost much less, since they entail far less labor.

First, there's no dictating or transcribing. Today's systems make it extremely easy for executives to enter and send their own messages, although senders must be willing and able to type the messages on keyboards. Second, postage costs can run as low as a dollar for instantaneous delivery of a 7500-character message. That's nearly four pages of text—much longer than the average business letter.

The first computer-based electronic mail products were a response by the timesharing services to growing competition from computer vendors. Early in data-processing history, computer users had two choices for applications software: to write their own or to rely on timesharing vendors to provide it. Gradually, however, computer vendors began to offer applications software as well as hardware. As more programs became available for in-house use, timesharing firms developed electronic mail services as one of several counterpunches.

In this market, the communications-oriented timesharing companies held an initial advantage over hardware manufacturers. By their nature, timesharing firms often interconnected multiple computer sites via communications networks. Although hardware vendors sold to multiple sites, they seldom connected them.

Pioneer electronic mail systems, such as Comet from Computer Corp. of America (Cambridge, Mass.) and On-Tyme from Tymshare (Cupertino, Cal.), aimed at the predominant sector of the messaging market: intracompany messages. The systems allow authorized users to exchange messages while avoiding "telephone tag" and postal service delays. However, messages sent via the services tend to be

by H. Paris Burstyn

short (four to six lines), because correcting typing errors on these systems is difficult.

As mainframe computers added office automation functions to their primary, calculative applications, hardware vendors recognized that their machines could effectively compete with the timesharing services for intracorporate communications customers. For sending messages within a single facility, it makes more sense to take advantage of the on-site computer than to dial up a remote computer, incurring additional communications and processing costs. To exploit this market, virtually every major hardware and third-party software house now offers electronic mail packages.

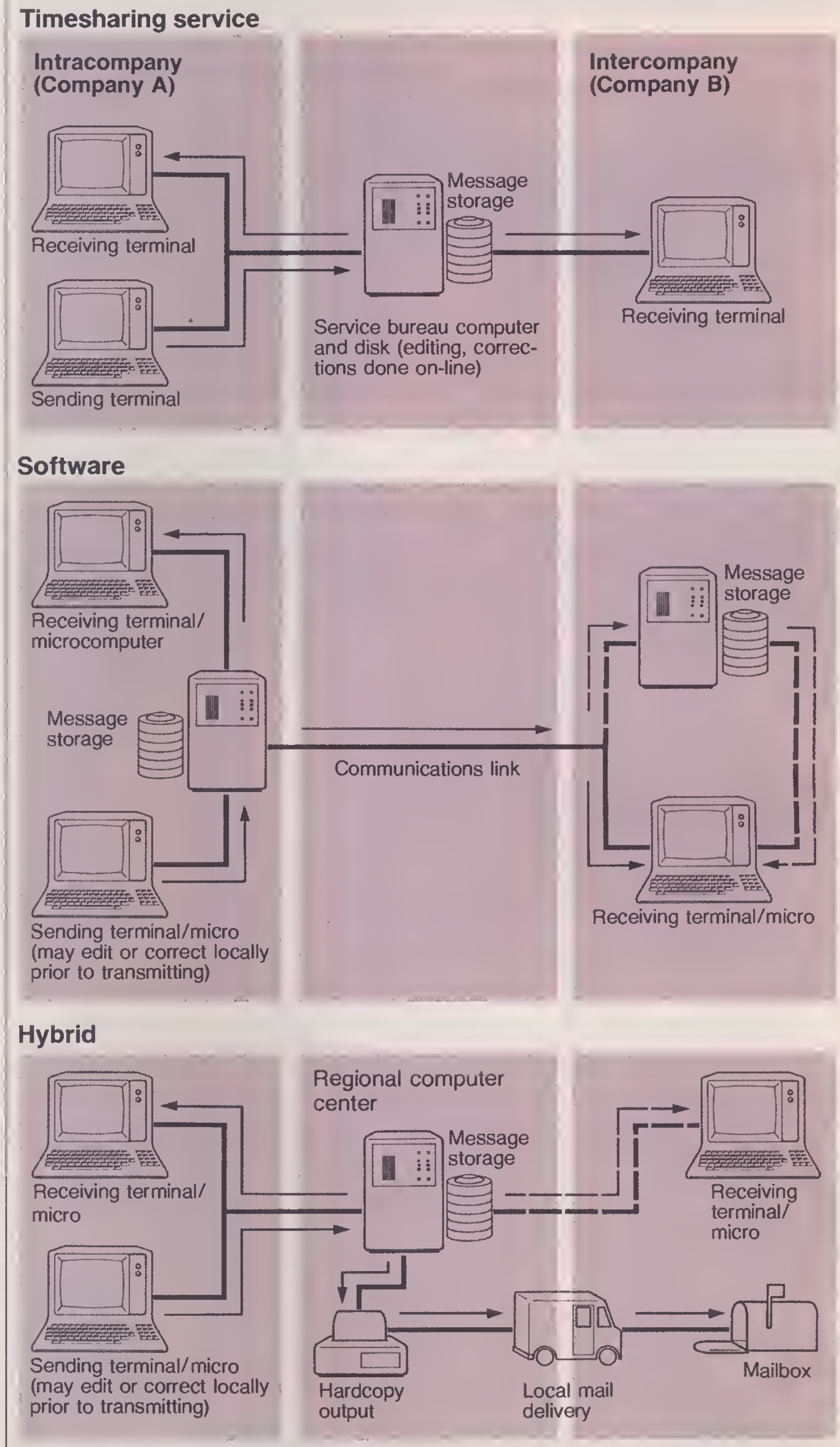
These software packages have limitations. While all provide comparable basic functions, most are aimed at specific computers and operating systems. Few are transportable between hosts. For example, IBM leases two primary electronic mail (electronic document distribution) systems. The Professional Office System (PROFS) runs only under the VM operating system. The Distributed Office Support System (DISOSS), runs under MVS or DOS/VSE. Terminal support also becomes a complex issue, since PROFS supports the 3270 line of terminals, and DISOSS supports terminals for the 8100 system (3732 and 8775 text display stations).

A few software houses offer packages that can run under different operating systems and even on different brands of computer. Infomail, from Bolt Beranek and Newman (Cambridge, Mass.), runs on DEC, IBM, and BBN hosts, and allows messages to be exchanged among machines of these three makes.

Currently the most visible type of electronic mail system is the hybrid. This approach, exemplified by MCI Mail, combines computer input with paper-based output options. Mailgram, the U.S. Postal Service's joint venture with Western Union, is the oldest example of such a system. Both the USPS and Western Union offer individual variations of this service (E-COM and EasyLink). But MCI, with its marketing expertise and large budget, has captured the most attention. MCI hopes to sign up 200,000 subscribers by the end of this year.

Since the subscription and usage costs for the hybrid systems are relatively low (see "The cost of electronic mail"), anyone with a digital input device can use the systems to send messages to virtually any address recognized by a traditional postal service.

Like timesharing-based message services, hybrid system providers maintain computers and communications networks to which users gain access



Three categories of electronic mail are timesharing services, software packages for in-house computer systems, and hybrids, which provide electronic and physical mail delivery options. With timesharing and hybrid systems, users must access an outside computer even if messages are to be sent within the company. A business running electronic mail software on its own computers avoids external communications links and costs, unless messages are sent outside the firm.

MARK E. ALSOP

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The cost of electronic mail

Most major computer vendors offer electronic mail products of varying cost to run on their machines. These software packages, for the most part, share a core group of features but provide a few variations, depending on the supplier. Owners of Data General, Datapoint, DEC, IBM, and Wang computers can get integrated office automation packages combining electronic mail communications facilities with office automation functions like word processing and document filing. Software houses and communications system firms also write electronic mail software, which may work under several different operating systems.

Prices for the mail systems can span a wide range. IBM leases PROFS for $600 a month plus a one-time fee of $4000. DISOSS mainframe software costs $1060 a month for the version that runs under MVS or DOS/VSE. An additional software package, 8100/DISOSS/DOSF, is required for IBM's 8100 computer so it can communicate with the DISOSS host. The package costs $187 a month or $3930 to buy.

The hybrids EasyLink and MCI Mail are structured differently. EasyLink charges a $35 a month account fee and $1.50 for each mailbox. Message rates vary between 25¢ and 50¢, depending on how the message is generated and delivered.

There are no sign-on, monthly, or usage charges for basic MCI Mail service. Instead, MCI charges "postage" for the messages sent. Postage costs are based on the MCI "ounce" (7500 characters). First-ounce prices vary, but each additional ounce costs $1. MCI provides four services:

• *Instant Letters* ($1/ounce) go to other MCI Mail users and are stored free of charge in their mailboxes for retrieval.

• *Letters* ($2/first ounce) are electronically generated and then printed by MCI for deposit into the USPS first-class mail system. Delivery usually takes two days.

• *Overnight Letters* ($6/first ounce) are delivered by Purolator Courier by noon the next day.

• *Four-Hour Letters* ($25/first ounce) are delivered by Purolator within four hours of being mailed. Service is limited to a 25-mile radius around some 15 U.S. cities.

Public electronic mail services are available from virtually all major time-sharing and value-added network companies. Among the prominent services are Computer Corp. of America's Comet, CompuServe, GTE Telenet's Telemail, ITT Dialcom, The Source, and Tymshare's OnTyme II. Monthly minimum charges range from $10 to $500. These companies also charge for connect time, message storage, and such services as database access or data processing.

through their terminals or microcomputers. Users write messages on-line or transmit precreated messages to the host computer center nearest the recipient's address. The center then prints the message and sends it to a machine that puts it into an envelope and conveys it to the specified delivery system. The hybrids use the postal system and other couriers for local delivery; users may choose delivery options according to price and priority.

The three generic types of electronic mail system—service, software, and hybrid—represent the foundations for the growth of universal electronic mail. Users will want to reach anyone, anywhere, regardless of the type of electronic mail system used. Intercompany links will become as important as intracompany links, and will help speed order processing, improve inventory control, and establish direct-payment channels for a multiplicity of transactions.

This market trend will force shifts in orientation for the service providers. User-owned electronic mail systems will pick up the bulk of intracorporate mail and will drive public services and hybrid systems to provide intercompany messaging facilities. Links, or "gateways," will be developed to allow connections between services, software, and hybrids.

The coexistence in some corporations of two voice communications networks provides a scenario for the evolution of electronic mail. Many companies install private tieline networks for intracorporate communications and use the public switched telephone network (PSTN) for outside communications. Employees receive two telephone numbers: one for the tieline system and one for the PSTN. One phone gives access to both.

Electronic mail systems will evolve similarly. Employees will have a single terminal providing access to the requisite electronic mail systems: an internal system for intracompany messages and at least one other for external, intercompany service. During the early stages, users might need multiple public mailboxes to accommodate correspondents with mailboxes on different systems. But as market requirements develop, public electronic mail services will begin providing gateways between systems.

This evolution will require electronic mail services to shift their focus. Although the overall number of network-resident mailboxes will increase (to accommodate the rising volume of intercompany mail), the services will experience a drop in network traffic as users employ their own systems for the bulk of their communications (since most messages will continue to be sent internally). To respond to this market-forced change in business direction, and to counter the drop in their overall traffic, network services will provide new capabilities such as gateways and transactional applications.

Aside from their primary messaging functions, electronic mail systems can offer other benefits that help justify them. Some in-house system users can access the internal database, incorporate needed information into messages, and send them to fellow workers. Public service users not only can send messages but can access such databases as the UPI Newswire, Dow Jones, and the Official Airline Guide.

Although these additional capabilities exist on some systems today, in many cases they are cumbersome, and require multiple sign-ons and data reformatting. With as many as three vendors to deal with, businesses today hesitate before attempting to justify costs. Instead they choose one system that best suits their general, or predominant, messaging needs. But when user-transparent gateways and centralized billing become commercially available, these services will prompt a great influx of electonic mail users. □

H. Paris Burstyn is an analyst with the World Telecommunications Information Program at the consulting firm Arthur D. Little (Cambridge, Mass.).

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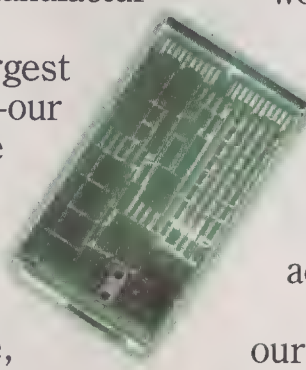

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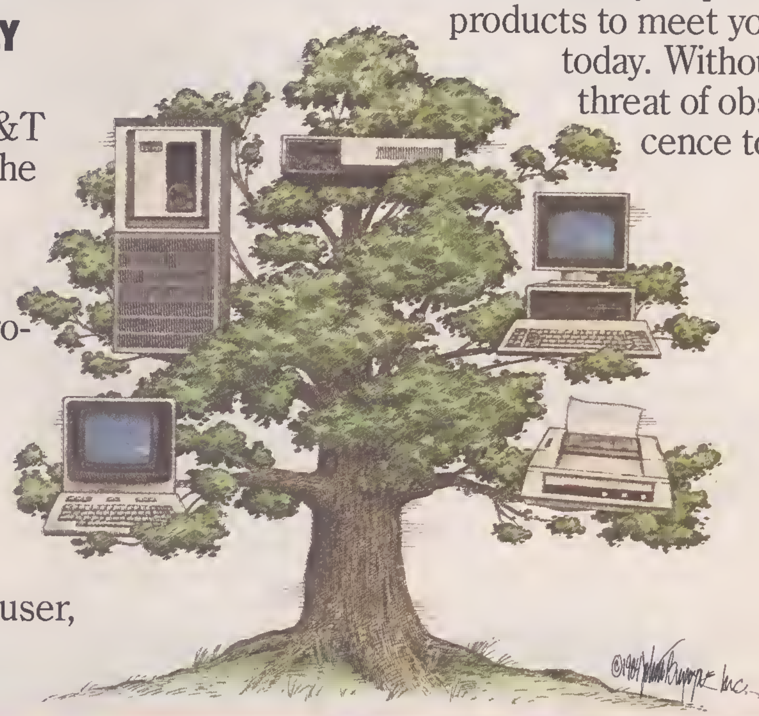

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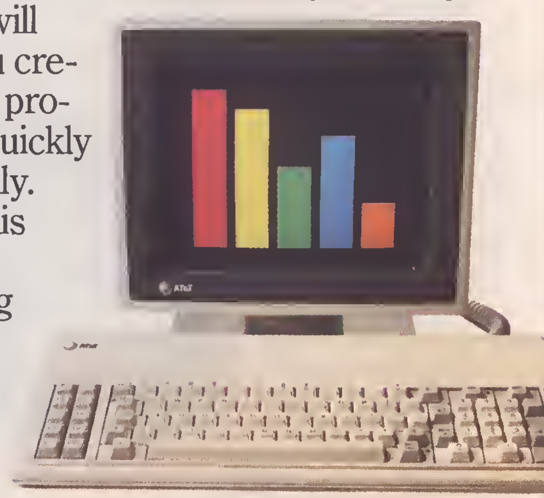

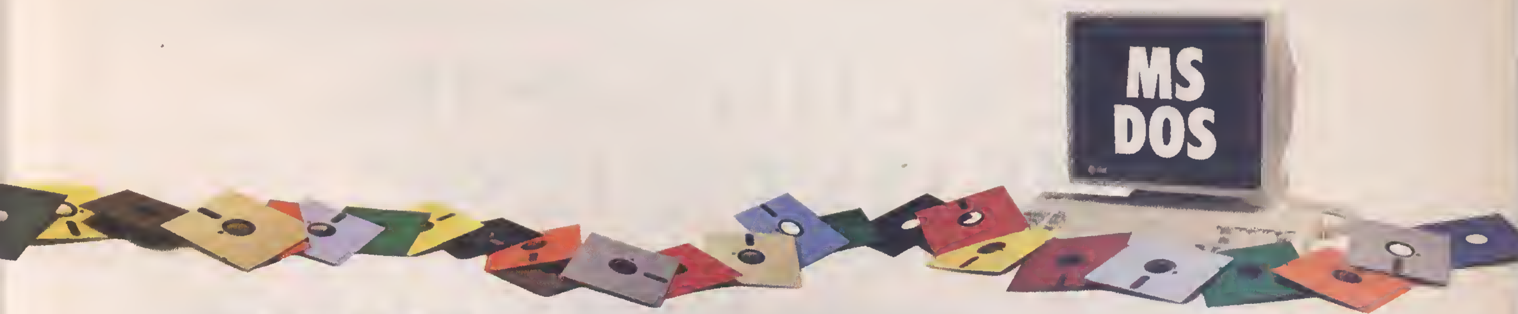

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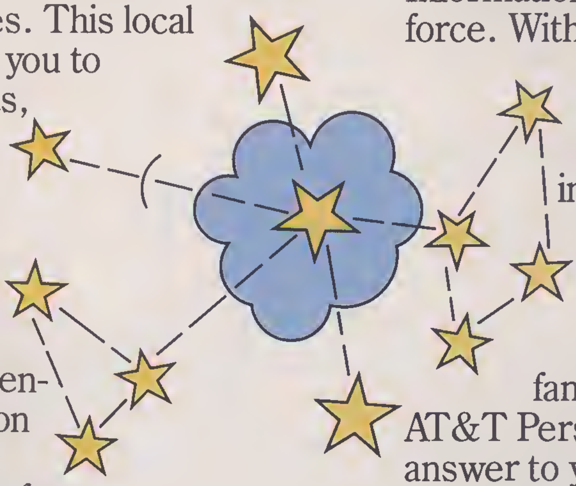

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"YOUR CHECK IS IN... THE PHONE LINE"

Bankers embrace home services, but consumers need convincing

Videotex-like services that let consumers do all their banking without leaving home have so far stirred more interest among banks than among consumers. Banks are developing and marketing the services with the hope of reducing staff, facilities, and check-processing burdens. Despite the technological glamour, though, consumer response to initial offerings has been tepid. Unlike the automated teller machines (ATMs), online bill payment and checkbook balancing have not struck the public as being worth the trouble.

Over 1000 banks and other institutions are said to be planning home banking projects. But just a handful now market a service, and only a few dozen more are in the pilot stage. Two of the most successful projects are Bank of America's in San Francisco, with 8000 subscribers, and Chemical Bank's Pronto in the New York City area, with 5000. Other ambitious projects are Viewtron—a Knight-Ridder videotex service available in the Miami area—Times Mirror in Orange County, Cal., and Keycom in Chicago.

Other giants loom: J. C. Penney is expected to take a leading role in home banking and videotex when its service is introduced, perhaps later this year, and Sears recently announced a joint videotex venture with CBS and IBM in which financial services are expected to figure prominently.

To initiate a home banking session, the user dials a local or toll-free number to reach the service's computer, which communicates with a home personal computer or videotex terminal through a modem. Menus displayed on the home screen help the user obtain account balances, transfer money between accounts, track checks, and pay bills to previously specified merchants. Some services also let the user apply for loans, purchase certificates of deposit, balance home budgets, and query bank officials.

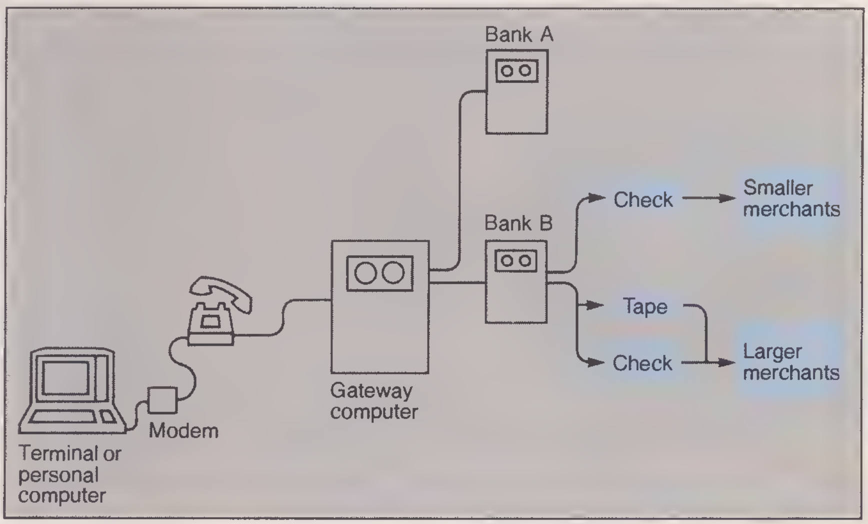
The home terminal talks to the bank's computer via an intermediate computer called a gateway. This machine, which isn't necessarily run by the bank, takes care of all the networking details like verifying passwords and enforcing protocols. Some gateways remain continuously tied in to the bank's computer so they can adjust account balances as transactions occur, with little or no delay. Most gateways, however, deal instead with "strip files," sets of working records adjusted nightly to reflect the day's transactions. In most cases, therefore, the user can access information current only to the previous afternoon.

Bill paying is less direct. For institutions or merchants that receive a large number of payments—a utility, say—the bank sends payments daily in the form of a single lump-sum check accompanied by a computer tape detailing who paid what. Otherwise the bill payer must allow five days for the bank to write and mail a check.

The push for home banking comes mainly from the banks themselves. Consumers write 36 billion checks a year; electronic bill paying could eliminate two-thirds of these, so banks could lay off tellers and use fewer check-processing machines. If enough customers went on-line, a bank could even close some branch offices.

But banks have a long way to go before they can realize savings from home services. There are two impediments: high initial cost (Chemical Bank spent $20 million developing Pronto) and weak consumer demand.

To reduce start-up costs, most banks share development efforts or license packaged systems. Video Financial Services (Miami) is a banking wholesaler owned by four bank holding companies; it provides Viewtron's banking operations, and will run home banking for Times Mirror and Keycom. Home Banking Interchange (Charlotte, N.C.) is an alliance of 17 U.S. and Canadian banks interested in exploring home banking. The association is sponsoring a nationwide, 2000-home trial managed by ADP Telephone Computing



Home banking services use gateway computers to relay information between a user and a bank. The gateway computer gets information on the user's account either by communicating directly with the bank's computer or, more often, by maintaining files of its own that are updated nightly. Fund transfers made via home banking are processed by the bank's computers. When the user requests a bill payment, the bank usually mails a check to the creditor within five days. Businesses receiving many payments can arrange for the bank to send a daily tape of bill payments accompanied by a single, lump-sum check.

MICHAEL ORZECH

by David H. Freedman

Services (Seattle). Chemical Bank has licensed its software to eight banks at $100,000 a shot. CompuServe, a leading vendor of on-line information services for personal computer owners, has put four banks on its system for over $30,000 each.

A bank typically needs 15% of its customers on-line for a home service just to break even; under present trends, that won't occur until well into the '90s. And even in the most widely used services, less than 1% of the consumers with access are regular users.

Consumer coolness stems from several problems, both real and imagined. A big one is that nobody has figured out how to send cash over the phone lines, meaning trips to the bank or ATM are still necessary.

Another barrier to acceptance is cost—typically $12 a month for the more complete services. And that doesn't count the phone charges, which could be considerable; most of the newly divested phone companies plan to start charging for each local call, similar to long-distance billing. The average computer-to-computer call lasts half an hour, 10 times longer than an average human conversation; many households would have to rent a second phone line to accommodate home banking.

Discomfort with computers is often claimed to lurk behind the resistance to home banking. A frequent assumption is that when this temporary uneasiness subsides things will change. Yet of CompuServe's 80,000 active subscribers—most of whom are presumably comfortable with the technology, since they own computers and modems—only about 1000 use the banking services.

Some of the blame for home banking's less than spectacular showing can go to consumers' misperceptions. Although home banking services eliminate that helpful five- to ten-day "float" that comes with writing a check, users are allowed to postdate bill payments up to 30 days. And contrary to popular suspicion, the systems do not police your transactions; a missed mortgage payment, for instance, won't cause the bank to reach into your checking account to settle the score.

Home banking users can pay their bills via electronic fund transfers, then check their account balances as shown on this screen from the J. C. Penney service.

Security is a more legitimate concern. Home banking services typically provide four layers of password protection, but the first two are routinely breached on "electronic bulletin boards" that are open to anyone with a microcomputer, a modem, and a subscription to one of several popular database services (e.g., CompuServe). Viewtron home bankers can voluntarily disable the lower password levels, saving themselves a few keystrokes but propping open the door for an electronic thief.

A thorny legal question arises here: Who is liable for the loss if a thief enters a system through a user-disabled password? The user, who probably ignored bank instructions, or the bank, which designed an easily defeated system? No precedent has been established in court, and banks don't like to discuss the issue.

Some banking systems embed passwords unknown to the user on the user's disk, cartridge, or terminal memory. Pronto, for example, hides a password in the cartridge; Viewtron builds passwords into the AT&T Sceptre terminals it sells to its customers. Such measures do little good, though, if the terminal or disk is stolen. Moreover, a clever microcomputer hacker can generate signals that emulate these embedded passwords and thus gain unauthorized access. To protect against phone tappers, Viewtron encrypts all transmissions, but the codes aren't good enough to stymie a sophisticated thief.

"Smart cards," plastic plates with embedded computer chips, are a possible solution. The user would insert the card into a reader connected to the terminal. A code stored in the card's memory, in combination with an identification number that the user typed in, would work as a unique "signature" to open the system for business. Also, the card's logic chip could encrypt data, for an extra dollop of security. The first test of the smart card for home banking will likely be J. C. Penney's Firsthand videotex service, which may go on-line later this year.

Another precaution is already in effect. Before being able to pay bills via a terminal, a user must give the bank a signed list of creditors. The bank will allow payments only to parties on the list. This requirement would prevent someone who had broken into a home banking account from authorizing payments to himself or a fictitious firm. Paper check writing is much more susceptible to fraud, banks say.

Banks are trying a number of tactics to entice people to use home services. All heavily subsidize the price; the $12-per-month charge covers barely a third of the cost. Services based on videotex terminals must also subsidize the price of the terminal. Viewtron sells the Sceptre terminal for $600—well under cost—though that will rise to $900 later this year.

Some banks make their services compatible with equipment many consumers already own, figuring that people are more likely to sign on if they don't have to buy hardware first. Pronto, for example, works with a a $70 Atari 400 computer and a videogame-style cartridge; Chemical Bank sells users a modem for $75.

Terminals are more rugged and easier to use than computers, and can receive graphics; prices, though high now, should plunge to $100 or so within a few years. J. C. Penney is expected to go with a terminal; Sears, with personal computers (hardly surprising, in view of its association with IBM).

Smart cards have been considered for some of the home services. The card's embedded memory chip could retain account balances and summaries of recent transactions to serve as

an electronic passbook. However, the cost of the read/write machines (about $100) has dampened enthusiasm for the idea; no operating banking service uses smart cards for record keeping.

Home banking can also be made more appealing to consumers when packaged with other information services, such as news, stock trading, entertainment, travel, and teleshopping. Most banking-only providers plan to add other on-line services eventually, making bank-run systems indistinguishable from videotex services offered by nonbanking institutions.

There's a crucial difference, however, from the bank's point of view: When the bank runs the show, it does not have to worry about competitors hawking their own money-market, IRA, or discount brokerage services. Sears is seen as particularly threatening, having acquired the Dean Witter Reynolds brokerage and the California-based Allstate Savings and Loan Association. The giant retailer is looking to acquire banks in a number of other states to get around federal laws that prohibit interstate deposits.

Other incentives for home banking will come as videotex services pick up speed. Slow, line-by-line transmission is giving way to the capability of quickly transferring an entire large file or program into the home subscriber's intelligent terminal. In addition to freeing up phone lines, such "downloading" would let the user run bank account data through financial management and tax-preparation programs residing on disk or cartridge. Financial programs are available now for personal computers, but many people balk at entering the data manually.

Perhaps the biggest boost to home banking would come from widespread use of of "debit cards," already accepted by some stores in California. The magnetic-striped card is run through a special cash register that's connected by phone line with a bank; funds for the purchase are transferred electronically from the card holder's account to the store's account.

For many, debit cards could all but eliminate the need for cash. Because trips to the bank or ATM would therefore no longer be necessary, consumers could make all bank transactions in the comfort of their living rooms. □

David H. Freedman is an editor of Infosystems. *He has a physics degree and writes about various areas of technology.*

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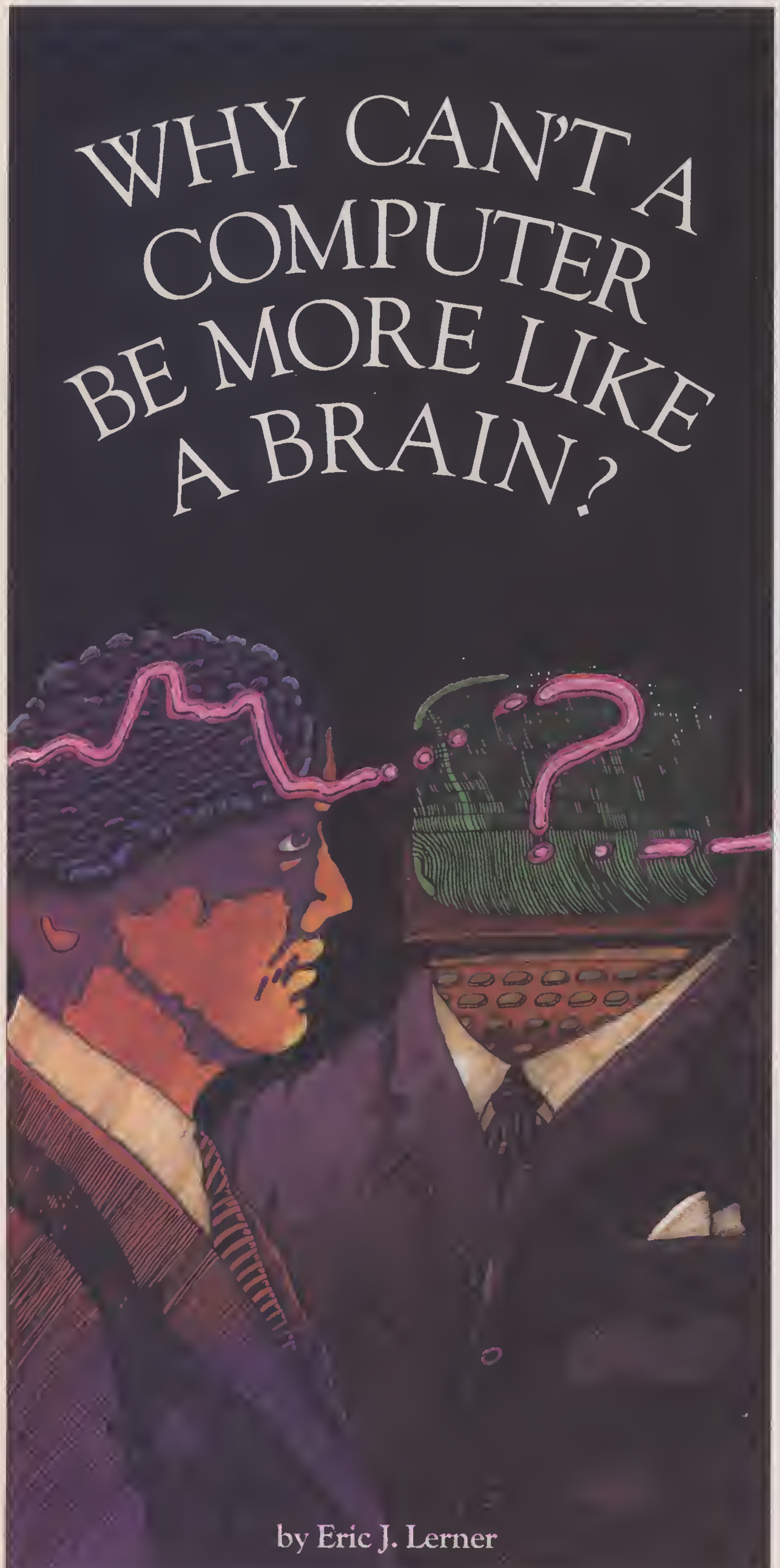
WHY CAN'T A COMPUTER BE MORE LIKE A BRAIN?



by Eric J. Lerner

Engineers seeking to develop truly intelligent computers have long looked to studies of the human brain in hope of imitating its processes. For example, they have known for some time that the brain, unlike today's digital computers, uses continuous variables rather than discrete binary (yes/no) variables. It's also known that the brain operates in a highly parallel rather than a serial fashion; that is, it performs many operations at once.

Two major research efforts are currently underway to bridge these gaps between computers and the brain. The well-financed Fifth Generation projects in Japan and the U.S. aim to develop computers with digital processors that function in parallel. In addition, "fuzzy set" theory is being applied to software design with the goal of enabling computers to make distinctions on the basis of continuous variables. A fuzzy set is one in which membership is not precisely specified—the set of "tall" people, for example. Using fuzzy sets, a computer program can imitate a human rule of thumb, such as "when the temperature is high, reduce fuel consumption a small amount," rather than a more specific rule such as "when the temperature exceeds 200°, reduce fuel consumption by 10%."

But both advances are limited insofar as they are superimposed on computer hardware that remains sequential and digital. In the case of parallel computers, these constraints lead to communications bottlenecks when individual processors transfer data. And in the software domain, programmers have run into barriers in their attempts to enable computers to generalize from experience and recognize similar but not identical situations. Designing computer vision systems that can perceive gestalts (inherently diffuse patterns) has also proved problematic. For example, an image made up of thousands of short arcs, all centered on the same point, is immediately recognizable by the eye as a circle. But a computer program, analyzing the individual arc segments, will have great difficulty in reaching that conclusion.

New approaches to these and other problems in artificial intelligence may someday emerge from a new theory of brain function now gaining favor among neuroscientists. Traditionally, the human brain has been seen as a vast switching network consisting of tens of billions of individual processing cells, called neurons, communicating with one another through electrical impulses. Since the early 1970s, however, a group of neuroscientists has challenged this model in favor of one that emphasizes neurons working together

ILLUSTRATIONS BY JAN SAWKA

in large groups and interacting with complex electromagnetic fields that pervade the brain.

According to this new model, known as cooperative action, thoughts and perceptions are encoded in the changing pattern of electromagnetic fields rather than the impulses of individual neurons. Moreover, the fields, generated by the synchronous activity of thousands or millions of neurons, are continually reflected back on the neurons themselves and in turn influence their activity. This new model may help explain the highly associative manner in which the human brain processes information and may inspire engineers to develop entirely new types of computers.

Feature extractor model. To understand the emerging model of brain function, it is necessary to survey some older theories. Ever since the 19th century, it has been known that neurons transmit electrochemical impulses from one to another via long fibers called axons. These impulses travel along the axon until they reach a junction, or synapse, with another neuron. At this point, chemical transmitters released from the axon terminal cross the gap and excite or inhibit the target neuron. If the excitation from several synaptic inputs exceeds a certain threshold, the target neuron generates an impulse of its own.

In the 19th century, when neuronal impulses were first studied, this picture of neurons sending all-or-nothing signals back and forth over wirelike axons was compared to a telegraphic system. With the development of digital computers after World War II, the brain was inevitably likened to a computer, although scientists even then recognized significant differences. For one thing, neuronal impulses, despite their all-or-nothing character, do not encode digital information. Studies of sensory neurons, which carry information from sense organs to the brain, have revealed that what is most significant about the impulses is their frequency: More rapid firing indicates a more intense sensation. Since the impulse frequency varies continuously, sensory neurons utilize a pulse-coded analog—not digital—form of information transfer.

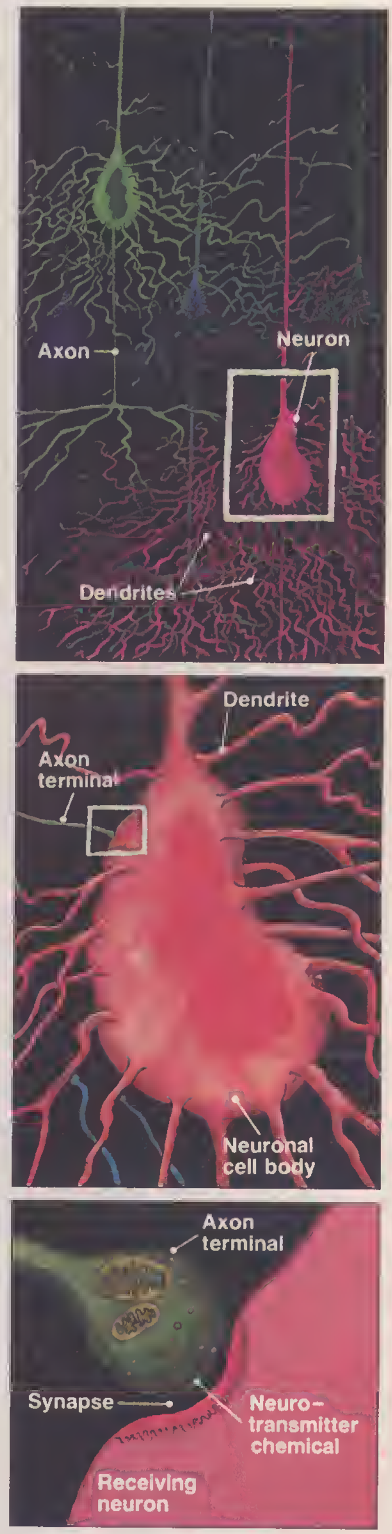
Nevertheless, most researchers continued to view the computer as a model for the brain. And just as the transistor is the basic unit of the computer, the individual neuron seemed to be the logical place to begin the study of brain function. The plan was to gradually build up from neurons to neuronal circuits, and finally to the organization of the brain as a whole.

In the early 1960s, David Hubel and Torston Wiesel of Harvard University found that in a cat's visual cortex (the part of the brain that processes visual information), they could identify a class of "simple" neurons whose firing rates were related to certain basic features of an image, such as the orientation of edges or bars. A second class of cells, labeled "complex," was sensitive to the direction of motion of edges. And a third class of cells, called "hypercomplex," responded to even more elaborate stimuli such as angles and corners (although these are still quite simple when compared with complete objects). This theory of neurons as feature extractors arranged in a hierarchy of responsiveness to increasingly complex stimuli became fundamental to much of the neurophysiological research that followed.

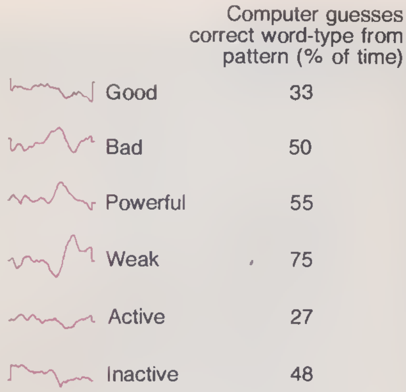
Almost as soon as the feature-extractor theory was formulated, however, it was challenged by a small group of brain scientists, among them E. Roy John, now at New York University Medical Center, and W. Ross Adey, now at the Loma Linda VA Hospital in California. These researchers argued that the concept was implausible because it presumed that at the top level of the hierarchy there were neurons devoted to incredibly specific tasks, such as recognizing a person's face.

Critics also pointed to specific ways in which the theory was contradicted by experiment. First, it failed to account for the brain's ability to recognize gestalt patterns that no single cell could possibly analyze. For example, stereograms made up of random dots present no coherent information when viewed with one eye, yet yield a vivid perception of a 3-D form when viewed with both eyes. Second, the feature-extractor model implied that information storage was localized in highly specialized neurons. Yet the results of operations in which large sections of the brain had been excised to treat cancer or epilepsy had demonstrated that individual memories were merely impaired—not destroyed—by surgery, and hence must be distributed throughout the brain. Third, if the simple feature-extractor cells fed information to more complex cells, the simple cells logically should have responded first. Yet in actual experiments, they often responded later.

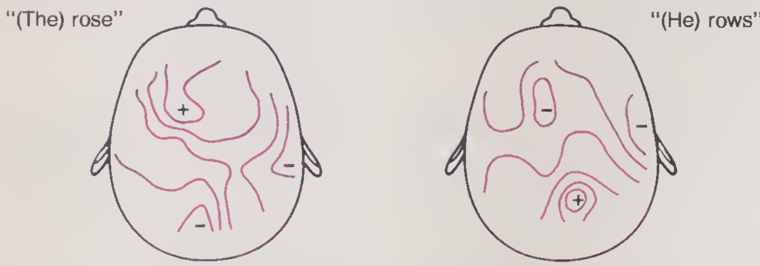
Finally, the behavior of feature-extractor cells was found to be less simple than the theory suggested. Hubel and Wiesel discovered that the firing rate of a given cell depended on not only the orientation of an edge but its length, velocity, distance from the observer, and other variables. Thus each cell fires in response to a range of stimuli, in-



Neurons, the brain's basic hardware, communicate at specialized junctions called synapses, inducing graded electrical potentials in the receiving cells. These potentials, summed over thousands or millions of neurons, give rise to a slow electromagnetic wave, or EEG, that pervades the brain.



Brain-wave patterns can be correlated with abstract mental concepts. In experiments performed by Robert Chapman and co-workers at the Univ. of Rochester, subjects were shown words grouped into six categories by connotation, including "good" words like beauty *and "bad" words like* crime. *Each word-type gave rise to a distinctive EEG pattern that could be recognized by a computer at a rate far better than chance.*



Warren Brown and his colleagues at UCLA recorded subjects' brain waves as they listened to identical-sounding words being used as both nouns and verbs, such as rows *and* rose. *When the EEG responses were averaged over many subjects, the brain-wave pattern produced by the noun was consistently different from that produced by the verb.*

stead of providing an unambiguous bit of information that can then be passed along for further analysis.

Cooperative action. The alternative model formulated by John, Adey, and a few others emphasizes the cooperative rather than the individual actions of neurons and the other types of brain cells. Just as the feature-extractor model had been inspired by the study of nerve impulses, the cooperative-action model grew out of the study of the electroencephalogram (EEG), or brain wave. The EEG is a slow electromagnetic wave that pervades the brain tissue; it can be recorded either with electrodes implanted in the brain or with an array of skin electrodes affixed to the scalp. While nerve impulses are individual voltage spikes, the EEG is a continuous wave, extending in frequency from one hertz (cycle per second) to a few kilohertz but concentrated in the range between 3 and 50 hertz. Clinicians have used brain-wave recordings for more than half a century to diagnose brain diseases.

Research in the 1960s demonstrated that the EEG arises not from the random summation of individual nerve impulses but from the slow, graded potentials produced by the neuronal cell bodies. When, as often happens, thousands or millions of neurons synchronize their slow-wave potentials, the result is the gross EEG. These waves then combine to form pervasive patterns within the brain, reinforcing at some points and interfering at others. Individual neurons are constantly slipping in and out of phase with the EEG field that surrounds them.

Although the feature-extractor model treats brain waves as nothing more than the background noise of the brain, experiments performed by John and Adey and by Soviet scientists demonstrated that EEG patterns can be correlated with high-level cognitive processes in both animals and human beings. Since the EEG is produced by large numbers of neurons acting in concert, these findings suggest that collective rather than individual neuronal activity is the basis of information processing in the brain.

Indeed, growing evidence lends support to the idea that electromagnetic fields play a role in brain function. But are these fields a reflection of collective neuronal activity, transmitters of information, or the embodiment of consciousness itself? There is a divergence of views on this question.

To some, even to many of those who subscribe to the cooperative-action model, the concept of information processing by electromagnetic fields seems implausible. Emanuel Donchin of the Univ. of Illinois believes that the waves are exclusively short-range phenomena carried from one cell to its neighbors, and that the large-scale electromagnetic fields associated with the EEG are incidental. Walter J. Freeman of the Univ. of California at Berkeley contends that cooperative action is mediated exclusively by neuronal impulses. He suggests that networks of inhibitory and excitatory connections among neurons set up natural oscillations that code neural information.

Perhaps the strongest advocate of the functional importance of electromagnetic fields is NYU's John. He contends not only that the EEG reflects brain activity but that the individual neurons are sensitive to the fields that they generate. Indeed, Adey and his co-workers have applied extremely weak electric fields (comparable in strength to the EEG) to the brains of experimental animals and have found that they alter the EEG predictably. Moreover, these changes are accompanied by specific behavioral effects, such as reduced reaction times.

John cites experiments he performed in 1980 in which pairs of electrodes were implanted in different areas of a cat's brain. The cat had previously been conditioned to turn left in a T-shaped maze to obtain a reward when it heard a tone repeated at a rate of twice per second, and to go right when it heard the tone repeated four times per second. John applied high-frequency electrical pulses to the electrode pairs, generating local electromagnetic fields in the animal's brain with strengths comparable to the intrinsic EEG. When the pulses were delivered in certain brain sites modulated at 2 hertz (twice per second), the cat turned left, and when the pulses were modulated at 4 hertz, the cat turned right. Since it was highly unlikely that the large electrodes were stimulating a discrete pathway, John concluded that the neurons of the cat's brain were acting cooperatively.

In a follow-up experiment on the cat, John fed a 2-hertz alternating current through one pair of electrodes and a second 2-hertz current through another pair, delaying the second signal by half a cycle. Thus the total input to the brain had a frequency of 4 hertz, but no one brain region received more than 2 hertz. The cat responded as if it were perceiving a 4-hertz tone, and the EEG recorded from its brain had a 4-hertz component. John concluded that the electromagnetic field as a whole was carrying information and determining the animal's perceptions.

According to John's hypothesis, the overall pattern of electromagnetic

waves evoked by sensory stimuli "resonates" with previous patterns stored in memory. Just as a sound wave at a given frequency causes a tuning fork that is tuned to the same frequency to vibrate, the electromagnetic wave pattern associated with a familiar sensory stimulus causes millions of brain cells to generate a similar pattern that has somehow been stored in the chemical structure of these neurons. In the brain, resonance is nonlinear: Activation of a stored pattern occurs not only when the incoming wave pattern is identical but even when it is merely similar.

Thus the pattern of electromagnetic waves elicited by the response to a sensory stimulus—say, the perception of a friend's face—resonates with similar stored wave patterns laid down by previous experiences. The new patterns in turn trigger new resonances, bringing forth a chain of associations such as the friend's name or incidents from the past. John contends that it is this chain of associations that gives rise to the stream of conscious experience. "Consciousness is a property of these improbable distributions of energy in space and time, just as gravity is a property of matter," he says. "The neurons are essential to creating the energy pattern, but subjective experience is generated by the pattern itself, not by the individual neurons."

Moreover, as the new pattern of waves arises in the brain, it somehow modifies the chemical structure of the neurons, thereby laying down memories that can in turn be evoked by resonance at some later time. The chain of associations can also be converted back into nerve impulses that are transmitted to the appropriate muscles to yield a behavioral response.

Although the cooperative-action model is still lacking in many details, its broad outlines seem to fit what psychologists have learned about the associative nature of human thought and the brain's remarkable ability to detect complex patterns almost instantly, such as recognizing a familiar face in a crowd. It would be impractical for the more than 10 billion neurons in the brain to exchange information by one-to-one connections; either there would have to be an astronomical number of connections, or each signal would have to travel through several dozen intermediate synapses at great cost in time. But if neurons could communicate with one another via electromagnetic fields, as well as by nerve impulses, large populations of neurons would be able to communicate simultaneously.

Although the cooperative-action model was outlined by the mid-1970s, only since 1980 has there been a rapid expansion of research devoted to testing and elaborating the theory. This expansion has been facilitated by the development of highly sensitive arrays of scalp electrodes for recording brain waves, along with computer-based techniques for analyzing these electromagnetic waves at high resolution in space and time.

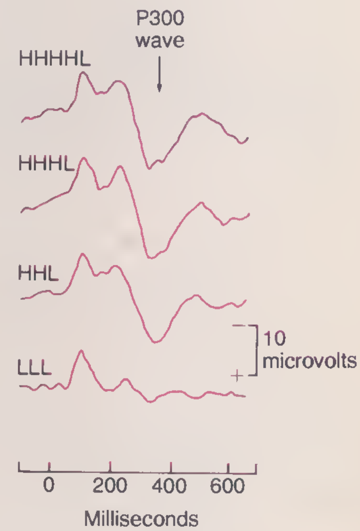
Evoked potentials. Several researchers are attempting to break the code that human and animal brains appear to use to represent sensory information, perceptions, and thoughts. These experiments are based on a technique known as evoked-potential recording. A sensory stimulus, such as a click or a light flash, is presented to the subject while the EEG is recorded. By averaging many such events, it is possible to cancel out the background activity of the brain and extract the electrical activity specifically associated with the stimulus. The result is a wave representing the brain's response.

A major focus of current research is to analyze the brain's response to language, and it is here that investigators have obtained some of the most striking results linking thoughts to brain-wave patterns. Robert M. Chapman and his co-workers at the Univ. of Rochester showed in 1980 that words with similar connotations give rise to similar brain-wave patterns, and that these patterns are fairly consistent in different human subjects. Chapman's findings suggest that there may be a universal language of the brain expressed in the EEG. If all words that connote "good" give rise to similar brain-wave patterns, then the occurrence of one such pattern in the brain could, in principle, call up the patterns of closely related words by the postulated resonance effect.

Other researchers have looked at how the pattern of electrical potentials shifts over space and time as the meaning of a word changes. Warren S. Brown and James T. Marsh of UCLA, together with Dietrich Lehman of the University Hospital in Zurich, Switzerland, recently recorded the brain waves of subjects while they listened to taped phrases in which the same word-sound was used alternately as a verb and a noun—for example, "a pretty rose" and "the boatman rows." These investigators found that different spatial and temporal patterns of the electromagnetic waves were generated in response to noun meanings and verb meanings. When subjects interpreted words as nouns, the potential fields peaked positively near the front of the brain and then negatively near the back. But when words were interpreted as verbs, the field pattern was reversed.

The brain also appears to encode visual information in patterns of electro-

A theory that the brain processes information with electromagnetic waves could give computer designers food for thought.

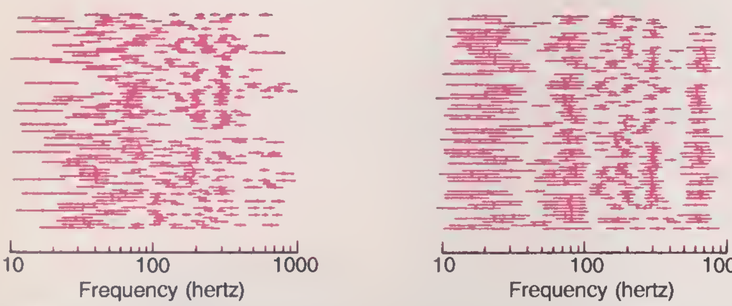


Emmanuel Donchin and his colleagues at the Univ. of Illinois recorded brain waves of subjects as they counted high-pitched (H) or low-pitched (L) tones in random sequences. When a series of low tones was followed by a high tone or vice-versa, a large positive wave appeared 300 milliseconds after the surprising stimulus (top). The less surprising the event, the smaller the P300 wave.

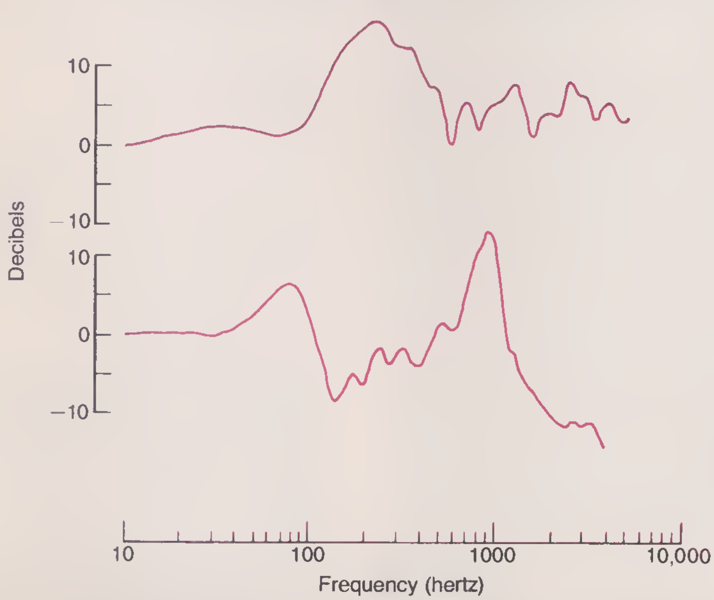
magnetic waves. Many researchers have noted that the ability of humans and animals to perceive gestalt properties of images is hard to explain with a feature-detector theory. Donald M. MacKay of the Univ. of Keele (England) has shown that consistent differences in evoked-potential waves can be correlated with an image's degree of "brokenness," even though individual neurons do not respond consistently to any degree of brokenness.

Decoding the brain. Unraveling the brain's method of coding information into electrical patterns is complicated by the fact that the brain generally reacts not to what it observes directly, but to the difference between what is expected and what actually occurs. This phenomenon, termed adaptation, is commonly observed in everyday life when oft-repeated or continuous sights and sounds fade from one's awareness. In effect, the brain is making hypotheses about the world, and it changes them when, from moment to moment, unexpected occurrences contradict these working models.

Fortunately, the adaptation process can serve as a tool to study how the brain changes its perceptions of the world. For example, Steven Hillyard and Mata Kutas of the Univ. of California at San Diego have found that if a subject reads a sentence that ends with an unexpected word, a negative wave shows up 400 milliseconds after the appearance of the word. This wave is called the N400 component. The closer in meaning the word is to the expected sentence ending, the smaller the N400 wave. For instance, if a subject reading the sentence "don't touch the wet . . . " expects to find the word *paint* but instead reads the unrelated word *dog*, there is a large N400 wave. Yet if the subject is reading "he likes sugar in his . . . " and expects the word *tea* but finds the related word *coffee*, the wave is much smaller. Thus the pattern of brain waves depends both on meaning and on what is expected.



Electrical field oscillations of the brain are concentrated in a few broad frequency bands (left). When stimulated by a specific event such as a 2000-hertz tone, the subject's brain-wave frequencies become more sharply focused (right). Data from Erol Basar, Institute of Physiology, Lübeck, West Germany.



The pattern of field oscillations in the brain depends on the type of sensory stimulus. As shown in tracings recorded by Basar, an auditory stimulus (top) gives rise to a pattern different from that of a visual stimulus (bottom).

While the N400 wave is seen only in response to unexpected linguistic meanings, surprising events of any sort elicit specific responses in the pattern of brain waves. Donchin and his colleagues at the Univ. of Illinois have studied the the P300 wave, the positive wave that appears about 300 milliseconds after any surprising event, such as a high tone after a series of low tones, or a male name after a series of female names. Again, the more surprising the event, the larger the P300 wave. The wave is also seen when an expected event fails to occur. Donchin and others have shown that the P300 wave does not occur merely when an event is surprising—the event must also be important to the task the subject is performing. Thus the P300 wave appears to be an indicator of the process by which the brain continually updates its model of the world in short-term memory.

While one group of researchers has been studying the way electromagnetic wave patterns encode information, another group has investigated how the brain generates and compares wave patterns, recognizing those that are similar. A leading investigators in this area is Erol Basar of the Institute for Physiology in Lübeck, West Germany. Basar has used a powerful computer to analyze EEG and evoked-potential waves into their frequency components. This work has shown that the normal EEG has a number of broad but sharply defined bands, centered on frequencies from 1 hertz to a few thousand hertz. The frequency bands vary somewhat from one part of the brain to another, but some are common to the entire brain.

Evoked potentials have a similar overall frequency structure to the EEG, but with some significant differences. The effect of a sensory stimulus is to bring the brain into a more coherent state. In response to the stimulus, the frequency bands in various parts of the brain become much sharper and narrower, and they move into phase and frequency coherence. This sort of "magnetic" behavior is typical of nonlinear oscillators found both in nature and in mechanical systems. Such oscillators respond to inputs of different strengths nonproportionately, yet are consistent in their behavior.

Basar has found that the smaller the amplitude of each frequency band immediately preceding a given stimulus, the greater the band's magnification following the stimulus. This effect may account in part for adaptation: The

more the brain expects a given state to continue, the less it reacts to stimuli that match its expectations. Basar has also shown that a repetitive stimulus sets up an "expectancy wave" that peaks at the time the stimulus is expected, even when the stimulus does not occur. This wave may therefore account for the major part of the P300 "surprise" wave.

The frequencies that are enhanced in an evoked-potential wave also depend on the stimulus itself. For example, Basar has found that auditory and visual stimuli give rise to grossly different frequency distributions of electromagnetic waves. To date, he has analyzed simple sensory stimuli such as clicks and flashes, but has not yet examined the brain's responses to more subtle stimuli such as tones and colors.

Chaos theory. If all of the information in the brain turns out to be encoded in the frequency spectrum and spatial distribution of the EEG, then the language of the brain may not be very different from a spoken language, which is encoded in changing spectra of sound waves.

Such systems of nonlinear oscillators are exceedingly difficult to analyze, because they shift suddenly from periodic, organized behavior to chaotic behavior. This is where a new field of mathematics known as chaos theory comes to the rescue. It describes how order, structure, and information can arise in these systems, and is currently being applied to a wide range of physical, chemical, and biological processes. According to chaos theory, nonlinear systems oscillate in specific patterns termed "strange attractors." Interestingly enough, Basar has shown that when the amplitude of one brain frequency is plotted against the amplitude of another, the graph exhibits the same type of

COMPUTERS AND THE BRAIN: AN A.I. PERSPECTIVE

by Jonathan B. Tucker

Investigators in the field of artificial intelligence (AI) agree that brain research could have much to offer designers of future computers. "Certainly the first step toward building a brainlike computer is understanding what the brain is up to," says Scott Fahlman, professor of computer science at Carnegie-Mellon University (Pittsburgh). "The brain is clearly using some tricks that we don't understand yet—it's more than just symbol processing on the von Neumann machine."

But current theories are still too vague and unproven to be of much help to computer designers today. "We know that the brain is highly connected and highly parallel, which certainly influences our computer architecture," says Daniel Hillis, cofounder of Thinking Machines, an AI firm in Waltham, Mass. "We also know that it's somewhat fault-tolerant, and designers of any big computer today have to take that into consideration." But beyond such basic concepts, Hillis adds, "so little is known about the brain that it's hard to draw many conclusions."

Marvin Minsky, professor of computer science at MIT, is also skeptical of the relevance of brain models to AI research—at least until more explicit theories are developed. The concept of information processing with electromagnetic fields "is a romantic idea that's been around for a long time, and nobody has ever demonstrated that it's as good as sending bits," he says. "If somebody wrote a program simulating such a system and got some interesting behavior out of it, then that might suggest a new way of designing a computer."

Nevertheless, a few efforts are underway to build computers that, in Minsky's words, "are based on theories of what a brain *ought* to do, although they don't have much to do with what is known about the brain." For example, Fahlman and two collaborators, computer scientist Geoffrey Hinton of Carnegie-Mellon and biophysicist Terry Sejnowsky of Johns Hopkins University, have developed a software simulation of a novel computer architecture called the Boltzmann Machine. This theoretical computer consists of a large number of processors that behave somewhat like neurons in the brain.

Each processor is connected to hundreds of others and is either "on" or "off" at any moment. The links between a processor and its neighbors are assigned numerical "weights" that can be either positive or negative. To decide whether to change its state, each processor sums the weights of the inputs it receives from other currently active processors and compares this sum with a threshold value. It then calculates its own state according to a probabilistic decision rule: If the sum is above the threshold, the processor usually (but not always) turns on; if the sum is below the threshold, the processor usually turns off; and if it is exactly equal to the threshold, the processor turns on half the time.

Because the activity of the individual processors is probabilistic, the behavior of the network as a whole can be analyzed with the same statistical formulas that describe the kinetic behavior of gases. For this reason, the simulated machine was named after Ludwig Boltzmann (1844–1906), an Austrian physicist whose research on gas thermodynamics led to the field of statistical mechanics. "The major new idea in this architecture is that by having a probabilistic decision rule for what a unit does, it actually becomes much easier to analyze the behavior of large networks," Hinton explains.

Information in the Boltzmann Machine is stored not in the individual processors but in their connections, which are represented mathematically by the numerical weights. "The weights are obviously meant to be like synapses," Hinton says. The Carnegie-Mellon researchers have also developed a learning algorithm that changes the strengths of those connections on the basis of experience, so that the Boltzmann Machine is theoretically capable of learning. "You just show it examples and it learns to build a model that explains those examples," Hinton says.

Although the Boltzmann Machine was clearly inspired by the brain, there are some basic differences between the simulated processors and real neurons. First, the processors are either on or off, whereas neurons communicate with pulse-coded trains of impulses. Second, the processors perform a simple addition of inputs, whereas information processing in neurons is considerably more complex. Third, the processors have symmetrical connections, while neurons have highly asymmetrical ones. Finally, in the computer simulations there is no time lag in sending a signal from one unit to another, yet in the brain there is a significant delay.

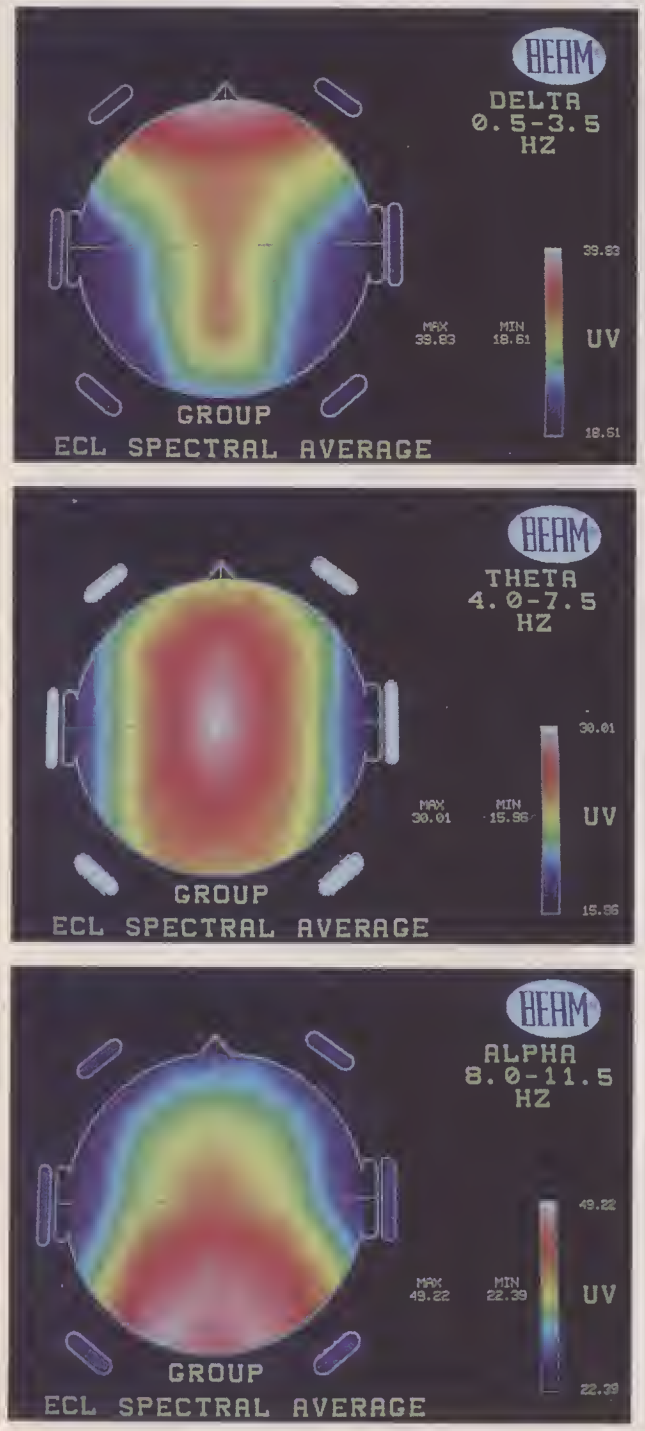
Fahlman and his co-workers are running simulations of Boltzmann Machines containing up to a few hundred processors, and they hope to increase that number to several thousand. But Hinton cautions that actual Boltzmann hardware won't be built for a long time. The main obstacle is that while a single neuron in the brain can handle more than 50,000 synaptic inputs, present microprocessors are limited to only about 64 leads.

strange attractor as is seen in chaotic physical systems such as turbulent flow in liquids.

This result indicates a statistical regularity in the relationship between the two frequencies that is characteristic of nonlinear oscillators. Moreover, nonlinear systems are fully deterministic yet unpredictable in detail: Although their behavior is governed by exact laws and not chance, infinitesimal differences in the states of the oscillators at any given time will lead to widely different behaviors in the future.

A number of efforts are now underway to extend the analysis of the brain as a collection of nonlinear oscillators to the cellular and molecular levels. Arnold J. Mandell, a psychiatrist at the Univ. of California at San Diego, has discovered that certain polypeptides (short protein chains) in the brain have natural oscillations between 1 and 1000 hertz. And Adey and Albert F. Lawrence at Loma Linda VA Hospital have proposed a tentative explanation for how neurons can respond to the ex-

Mapping the brain



Study of brain cells' collective electrical activity has relied heavily on computer-based techniques. One of the most important advances has been the mapping of the brain's electromagnetic fields at high spatial resolution with scalp electrodes.

Another promising approach is to map the magnetic rather than the electrical component of the fields. Although the brain's magnetic fields are only about a billionth the strength of the earth's magnetic field, a scanner known as a superconducting quantum interference device (SQUID) is sensitive enough to measure them. This device consists of two magnetic coils supercooled to 4° Kelvin (−453° F).

Lloyd Kaufman and Samuel Williamson at New York University, among others, have used a SQUID to map the EEG of human subjects with great accuracy. Because the brain and the skull are transparent to magnetic fields, high resolutions can be obtained at the surface of the head. The NYU team claims that magnetic sources can be traced to within a few tenths of a millimeter.

Recording the electromagnetic fields by implanting electrodes within the human brain is ethically justifiable only when needed to prepare a patient for brain surgery, and hence is done infrequently. In such cases, several electrodes spaced vertically along a single probe line reveal that the brain's field is complex: Different patterns can be detected by electrodes as close as a millimeter apart. Since other parts of the EEG are constant over wide areas, the field comprises both small and large features.

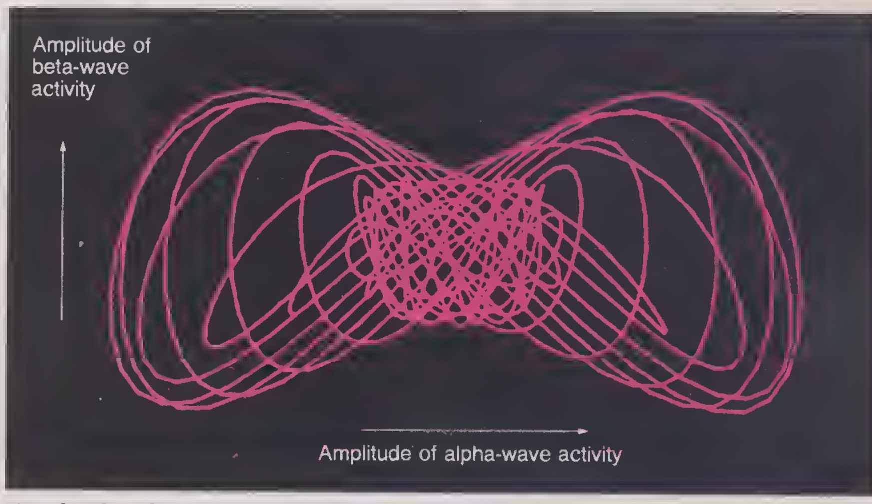
The same picture emerges from work with experimental animals, in which more extensive probing has been done. By identifying the sources and sinks of current flows, researchers can separate distant and local portions of the field oscillations. As more detailed and higher-resolution maps are developed, it may be possible to distinguish between phenomena associated with the highly variable small-scale fields and those associated with the coherent whole-brain fields. One hypothesis is that the small-scale variations are closely tied to sensations (the brain's map of the external world), while the whole-brain potentials are linked to the brain's inner processes (the monologue that goes on inside our heads).

System for visualizing brain waves, known as the Brain Electrical Activity Mapping (BEAM) machine, was developed by Frank H. Duffy and his co-workers at Children's Hospital Medical Center in Boston. The BEAM machine converts EEG data from a 20-electrode array on the scalp into a multicolor map of brain-wave activity. The images at left represent the average topographic distribution of three EEG frequency bands in a group of normal adults resting with eyes closed. Reading from top to bottom, the images show the distribution of delta waves, theta waves, and alpha waves. The color scale allows one to determine the intensity of the particular frequency band at any point on the head.

DR. FRANK DUFFY

tremely low electromagnetic fields of the EEG. Their theory is based on the fact that the outer membrane of the neuron has embedded within it stringy molecules called glycoproteins, which stick out from the cell surface like a field of wheat. Adey and Lawrence hypothesize that calcium ions bind to sections of these glycoproteins and convert them to a higher-energy conformation, like coiled springs. The ions appear to participate in chemical reactions that oscillate at characteristic frequencies. Thus when electromagnetic waves with frequencies close to those of the chemical oscillations impinge on the glycoproteins, they set up a resonant motion that shakes the ions loose, releasing far more energy than is contained in the waves themselves.

This theory is consistent with Adey's observations that weak external electric fields, modulated at frequencies close to the EEG, can alter the calcium balance of a cat's brain. But the theory remains tentative, and so far it does not explain how neurons can later modify their reactions to a given field in response to past experience—that is, how memories are formed and changed.



Amplitudes of two prominent frequencies in the EEG of a cat's brain—the alpha rhythm and the beta rhythm—were plotted against each other by Basar, yielding a figure-eight pattern known as a "strange attractor." This finding indicates that the various brain-wave frequencies are related in a complex but nonrandom manner.

Implications for computing. The new model of the brain as a set of nonlinear oscillators with a mediating electromagnetic field has important implications for the design of future computers. A computer based on these principles would, as stated, differ from existing machines in two fundamental ways. First, it would operate on continuous rather than discrete signals. Second, communication among its elements would be via electromagnetic waves spreading continuously through the network of computing elements, rather than by signals traveling along separate communication lines linking the individual elements.

This concept would make possible an entirely different approach to the problem of designing massively parallel computers. Although it is possible today to build many individual processors working in parallel, each processor functions sequentially: It takes a set of inputs, performs an operation on them, and then does the same to the next set of inputs. Thus communication of data between the various processors creates serious traffic problems. But if all the processors were connected through a continuous electromagnetic field, their contributions to the field would occur simultaneously and in a completely parallel manner.

Such a computer would also be inherently capable of generalizing from experience. For example, suppose the computer detected an object, such as a car, similar but not identical to one it had seen before. The stimulus would generate a pattern of electromagnetic waves similar in some respects to patterns that had already been stored in memory. Some of these stored patterns would be evoked by "resonance" with the sensory input, enabling the computer to recognize the object as a member of the "fuzzy set" of cars. Recognition could then trigger a behavioral response, such as moving a steering device on a vehicle to avoid a collision with an oncoming car.

A computer based on cooperative action would consist of hardware components that could convert an input from an external sensor into a pattern of oscillating electromagnetic waves. These components would produce a resonant wave pattern when exposed to wave patterns similar to those already stored in memory. They could also modify their own stored wave patterns to correspond with new ones from the outside world or from internal processes.

There are at least four theoretical approaches to the development of such "field-effect" computers. One approach would be to use microwave circuits built from conventional components: sets of nonlinear oscillators that could send and receive microwave information. This method might be simplest from a technological standpoint but would result in extremely complex and expensive machines.

A second approach would be to build the computer out of basic computing elements that function naturally as nonlinear oscillators. For example, Josephson junctions—superconducting devices that have been investigated as a possible basis for superfast computers—behave as nonlinear oscillators in the microwave region. But it would be necessary to overcome formidable technological problems owing to the fact that Josephson junctions operate only at liquid-helium temperatures.

A third approach would start with optical computing, the one form of computer technology that already uses electromagnetic fields. In optical computers, the interference of light waves is used to perform functions such as pattern recognition. Present optical technology uses only linear interactions, so that an image must be virtually identical to a stored model for the pattern recognition system to identify it. The introduction of controlled nonlinearity into such systems, permitting recognition of similar but nonidentical patterns, would be a very difficult task.

A final and even more speculative approach would be to build a computer based on molecular computing elements. Indeed, a small but growing research effort is focusing on the idea of molecular computers, in which individual molecules, rather than silicon microcircuits, would serve as the basic functional elements (HIGH TECHNOLOGY, Feb. 1984, p. 36). While most attention until now has focused on using molecules for switching, it is at least conceivable that, as in the brain, artificial arrangements of molecules could be made to respond as nonlinear oscillators to electromagnetic fields.

Although the development of such exotic computers remains in the realm of blue-sky ideas, increased knowledge of the human brain may well inspire computer designers to seek altogether new machines with intelligence and the ability to learn. □

Eric J. Lerner is a freelance journalist who writes extensively on science and technology.

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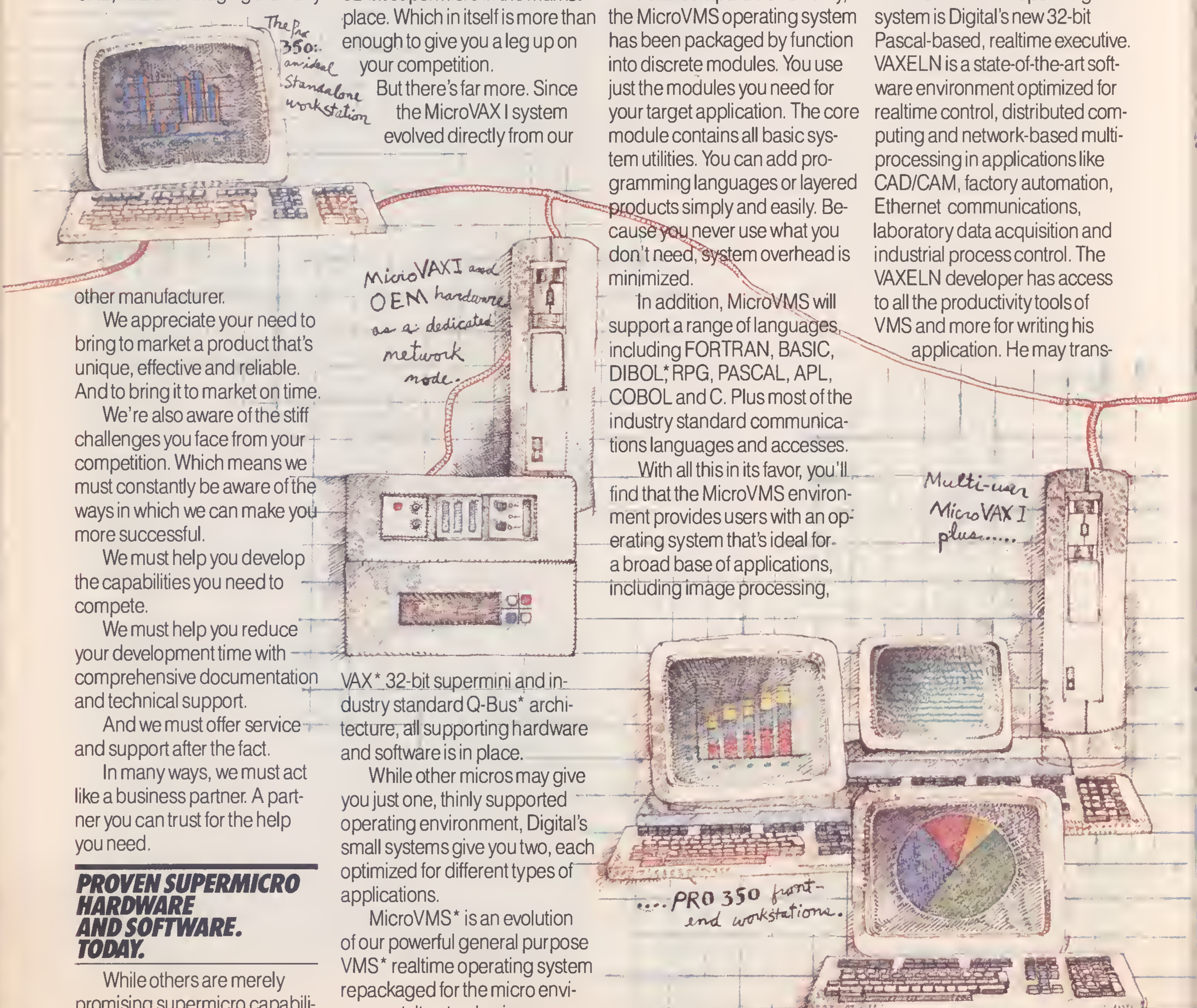
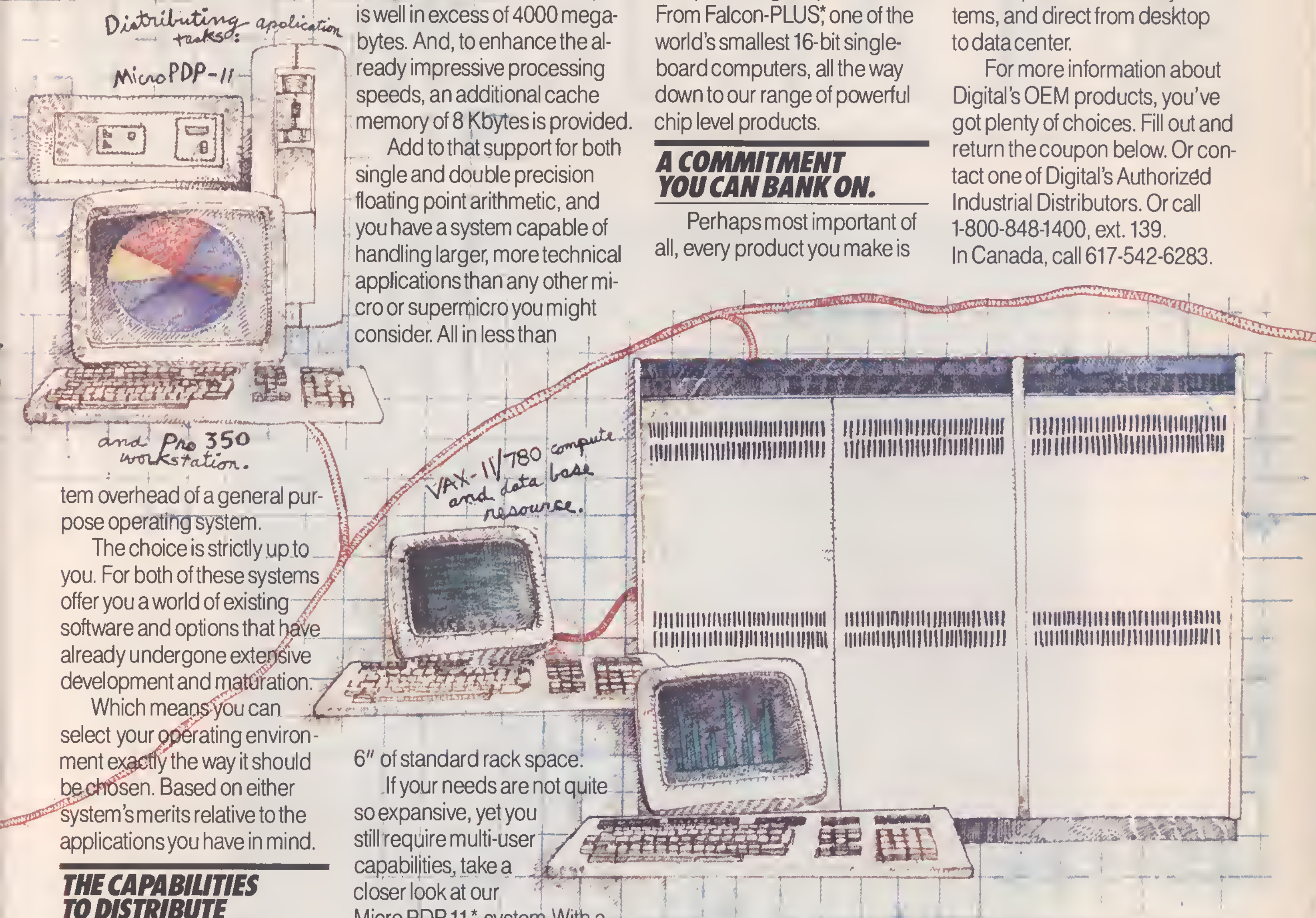


port it to other VAX or MicroVAX I target systems where it may be executed with none of the sys-



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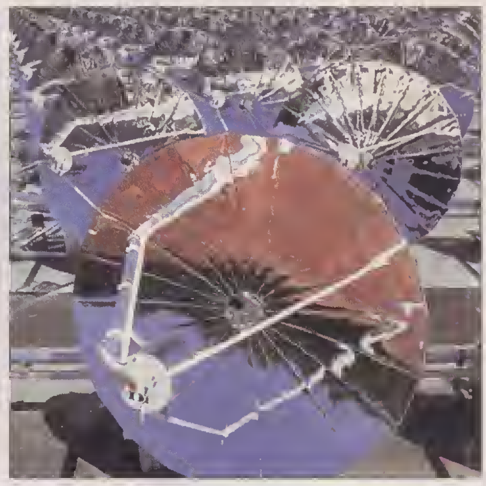


Far left: Large wind farm at Altamont Pass, Cal. (Photo by Ed Linton, U.S. Windpower, Inc.) Left: Parabolic mirror system at Shenandoah, Ga. (Photo courtesy of Georgia Power Co.)

Central-station photovoltaic plant at Carrisa Plain, Cal. Solar cells are mounted on trackers equipped with metal reflectors. (Photo courtesy of ARCO Solar.)

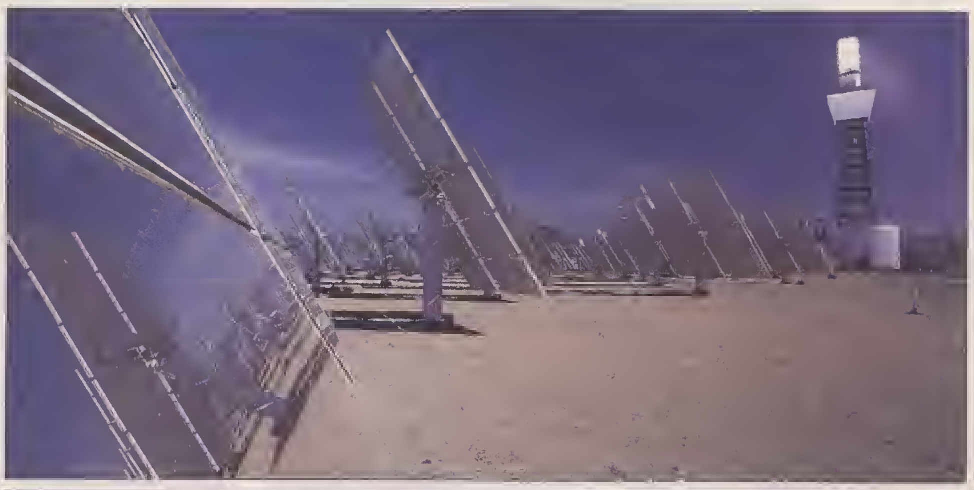
Electricity is a clean and versatile form of energy that will continue to grow in importance for lighting, heating, and cooling, and for powering our increasingly automated and computerized society. Although overall energy use in the United States has leveled off, demand for electricity is expected to grow at an average annual rate of 2.5% over the long term, according to the National Electrical Manufacturers Assoc.'s Ninth Biennial Survey of Power Equipment Requirements. Because energy policy planners generally agree that a mix of energy sources is required as a hedge against shortages in any one area, electric utilities around the United States are taking a second look at renewable generating technologies, particularly those based on the sun.

Every 15 minutes, the sun delivers to the earth enough radiant energy to meet all of mankind's power needs for a full year. But harnessing this energy is complicated by two properties of sunlight: its diffuseness and its variability with time of day, season, and weather conditions. These factors pose formidable technical challenges for the efficient conversion of solar radiation into bulk, utility-grade electric power. Nevertheless, solar technologies are attractive to utilities because they are environmentally benign and offer "a low regulatory risk, limited capital risk, and short lead times," says Steven L. Hester, a research engineer with Pacific Gas & Electric (PG&E—San Francisco). Since solar-power systems typically consist of arrays of discrete generating modules, utilities can increase capacity in small increments with limited financial commitment, instead of investing several years and large amounts of capital to build a major fossil-fuel or nuclear plant.

The world leader in the use of solar power is the state of California, which expects to obtain most of its additional generating capacity in the late 1980s and the 1990s from a variety of renewable sources; all coal and nuclear-power plants projected for that period have been canceled. California's leadership in solar power is due to its wealth of renewable resources such as sunshine,

GOES ON-LINE

and wind power are plugging into the U.S. utility grid ◆ by Jonathan B. Tucker



Sun-tracking mirrors at Solar One plant (Barstow, Cal.) focus sunlight onto a central receiver atop a tower.

Aerial view of Solar One. (Both photos by Peter Menzel.)

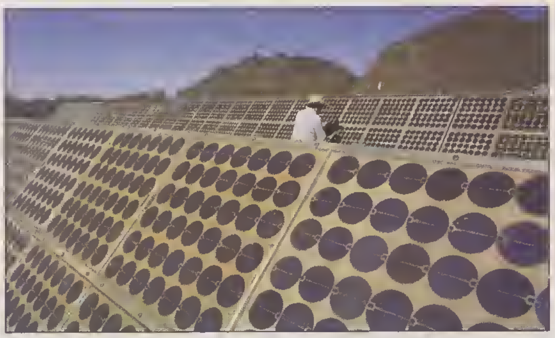
water, and wind, a favorable regulatory and political environment, and a combination of federal and state policies that give nonutility third parties a strong financial incentive to invest in renewable-energy systems that produce electricity for sale to local utilities.

The Public Utility Regulatory Policy Act (PURPA), passed by Congress in 1978, requires utilities to interconnect with and buy power from small producers of electric power (less than 80 megawatts capacity) and pay them the "full avoided cost"—the dollar amount the utility would otherwise have to pay to produce the power itself. In addition, the state of California provides a generous 25% investment tax credit for renewable-energy projects on top of the 15% federal tax credit, thereby limiting investment risk.

Although the power produced by solar plants is not yet competitive on U.S. utility grids without tax credits, rapid technological advances promise to reduce costs significantly over the next decade. Indeed, two recent studies done for the electric utility industry by Battelle-Columbus Research Laboratories (Columbus, Ohio) and the Electric Power Research Institute (EPRI—Palo Alto, Cal.) predict that certain solar-electric technologies will become economically viable for U.S. bulk-power markets by the early to late 1990s. Having recognized solar's potential, a number of major U.S. utilities are already testing large demonstration systems in collaboration with equipment manufacturers and government research labs. This effort is essential because solar-power plants—like any new source of electricity—will have to be tested for many years before utilities can be confident in their reliability.

The most rapid technological advances are being made in the area of silicon photovoltaic (PV) cells, which convert solar radiation directly into electricity. When photons of sunlight strike the cell, electrons are knocked free from silicon atoms and are drawn off by a grid of metal conductors, yielding a flow of direct current. Solar cells offer several advantages over conventional sources of electricity: They require no fuel, are self-contained, have

Fixed flat-plate PV array at Papago Indian Village in Gunsite, Ariz., comprises modules of single-crystal silicon solar cells. (Photo by Dan McCoy/ Rainbow.)



no moving parts, are nonpolluting in operation, and need little maintenance over a lifetime of 20 years or more.

Groups of PV cells are mounted onto a rigid plate and wired together to form modules—the building blocks of solar electric systems. A typical module has a surface area of half a square meter and a generating capacity of about 50 watts. The power output of a PV system is rated in kilowatts of peak power—that is, the wattage the cells would deliver when exposed to vertical rays of noon sunlight on a clear day. Virtually any power output can be supplied by mounting dozens of modules onto panels, which can in turn be combined into large arrays. Although PV systems will work almost anywhere, locations that receive less intense sunlight require larger arrays to generate the same amount of power. Thus a 1-kilowatt PV system will produce 2500 kilowatt-hours per year in the Southwest but only 1600 in New England or the Northwest.

Photovoltaic plants. Because of the low energy density of sunlight, a central-station PV plant requires an array field covering 10 to 20 acres of land for each megawatt of installed capacity. Power-conditioning equipment is also necessary: Solid-state inverters convert the direct current (dc) generated by the solar cells into alternating current (ac) compatible with the utility grid. Storage batteries are often used to smooth power fluctuations caused by clouds.

At present, large, central-station PV plants for generating bulk utility power are more economical than rooftop systems. "Because of the costs associated with marketing, distribution, and connection to the utility grid, the price of an installed consumer PV system can easily be three times as high as the factory price," explains Edgar A. DeMeo, manager of the Solar Power Systems Program at EPRI. "A utility buying modules in bulk can do much better; there might be an add-on of 50% rather than 200%." Although distribution of electricity from central-station plants involves transmission losses, these are usually no more than 10%.

Central-station PV arrays are of three types: fixed flat-plate, tracking, and tracking-concentrator. While fixed flat-plate arrays are the least expensive and require minimal maintenance, microprocessor-controlled equipment that enables the modules to follow the sun as it moves across the sky can increase power output by as much as 40%. The higher capital cost of tracking systems is offset by their increased power output; it is not yet known whether maintenance costs will be substantially increased.

Tracking-concentrator systems include mirrors or lenses that focus the sun's rays onto the modules, boosting their power output by a factor of 50 or more. Since tracking-concentrator systems can collect only direct rays, they work well in the southwestern U.S. but poorly in the Southeast, where humidity and cloudiness make solar radiation more diffuse.

The first privately funded central-station PV plant, known as Lugo Station, was built over a seven-month period in 1982 by ARCO Solar (Woodland Hills, Cal.) on the high desert near Hesperia, Cal. The 1-megawatt plant is a field of 108 trackers covering 20 acres. Each tracker is 32 feet square, comprises 256 solar modules, and follows the sun along two axes. Ever since Lugo Station went on-line in November 1982, it has fed electricity into the distribution grid of Southern California Edison (SoCal Edison—Rosemead, Cal.). The plant is designed for unmanned operation, starting itself up at sunrise and shutting down at sunset. "Computers control the trackers and inverters, and we remotely monitor them through data lines," says Robert Tolbert, manager of major project operations for ARCO Solar. According to Tolbert, the system's reliability last year was better than 98%.

ARCO Solar is building two other central-station PV power plants in California. One is located on the Carrisa Plain, at an altitude of 2000 feet between San Luis Obispo and Bakersfield; when completed, it will produce a total of 16.5 megawatts of peak power for sale to PG&E. By mid-1984, 756 trackers erected over an area of 160 acres were producing roughly 6 megawatts of peak power. The other PV plant under construction is the first phase of what may eventually become a 100-megawatt facility for the Sacramento Municipal Utility District (SMUD). Roughly 40% of the initial 1-megawatt installation—about 50 single-axis trackers—went online June 15, according to project manager Mark Anderson.

Cost barrier. About half the cost of today's PV systems is for the solar modules themselves; the remainder—referred to as the balance-of-system (BOS) cost—stems from the structures that support the modules, power-conditioning equipment (electrical inverters, batteries, and wiring), site preparation, engineering fees, and so forth. Improved building techniques and materials have already slashed BOS costs to less than $2 a watt, according to Jerry Noel, project manager for solar energy materials and devices at Battelle Columbus Labs. But although BOS costs have come down sharply, the major hurdle remains the price of the PV modules themselves.

The cost of silicon solar modules has dropped from nearly $20 per peak watt in 1977 to about $7–8 per peak watt if bought in small quantities, and about $5 per peak watt if bought in megawatt quantities. These prices are already competitive for remote applications (more than a mile from existing distribution lines), but if PVs are to compete in U.S. bulk-power markets, much lower module prices will be required. The U.S. Dept. of Energy (DOE) has targeted a cost of about 70¢ per peak watt (in 1982 dollars) as the point at which PVs will become competitive with natural gas and oil for generating peak-hour electric power. "If solar cells can meet DOE cost goals by the 1990s, then in certain locations solar photovoltaics will be a competitive technology," says William R. Huss, principal research scientist in the energy economics group at Battelle Columbus Labs.

The single-crystal silicon solar cells used today are costly because they require large amounts of highly purified silicon and are manufactured by a batch process. These cells contain silicon in a highly ordered crystalline form, in which each atom is bonded to four neighbors. In an effort to reduce costs, alternative development paths are being pursued, including thin films made of amorphous silicon. Unlike

crystalline silicon, amorphous silicon is a glasslike material in which the atoms are randomly bonded to one another and not all bonding sites are occupied.

Amorphous silicon absorbs light so efficiently that a film 1 micron thick—less than 1/20 the thickness of a piece of paper—can function as a solar cell. Such films are relatively inexpensive because they use about 1/600 of the silicon in a conventional wafer device. They can also be manufactured automatically and at much lower temperatures by one of two processes—glow discharge or chemical vapor deposition—in which a silicon-hydrogen gas is deposited onto an inexpensive substrate of glass, thin metal, or plastic sheet. An advantage of this approach is that the thin layer of amorphous silicon can be applied over large surface areas.

Six companies in the United States are engaged in R&D on amorphous-silicon solar cells. Factories capable of manufacturing some 10 megawatts of cells a year are in various stages of construction, according to Paul Maycock, president of Photovoltaic Energy Systems, a consulting firm in Alexandria, Va. ARCO Solar has a small pilot production facility and will begin to market cells late this year. Solarex (Rockville, Md.) acquired RCA's amorphous-silicon technology and is preparing to manufacture solar modules for power use. Chronar (Princeton, N.J.) has three plants under construction, each of which will be capable of producing about 1 megawatt of amorphous-silicon solar cells annually. Energy Conversion Devices (Troy, Mich.) has built a plant with Sharp in Japan and is now producing 1.5 megawatts of solar cells per year; a new plant in Michigan, financed in partnership with Standard Oil of Ohio, will start production this fall. In addition, two other companies, Spire (Bedford, Mass.) and 3M (Minneapolis) have received contracts from the DOE to develop amorphous-silicon technology. Meanwhile, several Japanese firms, led by Sanyo, Sharp, and Fuji Electric, have begun to produce amorphous-silicon cells in commercial quantities.

Improving efficiency. The drawback of amorphous-silicon thin films is their low conversion efficiency—about half the 11% characteristic of single-crystal silicon cells. Although amorphous-silicon thin films have achieved efficiencies in the lab of about 10% over small areas, their efficiency drops to 3–5% when the cells are scaled up in production to module size.

According to PG&E's Hester, module efficiencies of 10–15% are required for central-station PV plants. Lower efficiencies must be compensated for by increasing the number of modules, resulting in high BOS costs because of the extra structures needed to support them. Specifically, switching from an efficiency of 10% to one of 5% means that twice the area of solar modules is required to produce the same power output, which has the effect of doubling the area-related BOS costs (not including power conditioning) from about 75¢ per watt to $1.50.

Improving the efficiency of amorphous-silicon solar cells while keeping module costs low will require complex engineering trade-offs. "Clearly the goal is to get the most efficient system for a given dollar amount," says Leonard M. Magid, former head of the U.S. government's National Photovoltaic Conversion Program and now a principal consultant with PA Consulting Services (Princeton, N.J.) "You can afford to pay a higher price for more efficient solar cells because they produce additional power. But if improving the efficiency by 10–15% means doubling the cost, that won't necessarily fly."

Perhaps the most promising new PV technology is the "tandem," or "multijunction," cell, consisting of multiple layers of thin-film photovoltaic materials, each sensitive to a different part of the solar spectrum. Multijunction cells are not much more difficult to manufacture than single-layer cells and are theoretically capable of efficiencies of more than 30%.

Last October, the DOE-funded Solar Energy Research Institute (SERI) in Golden, Colo., launched a three-year, $18.6 million research program designed to accelerate the development of amorphous-silicon thin-film solar cells. The program is a cost-sharing arrangement in which SERI will provide approximately 70% of research expenses, and private subcontractors the remaining 30%. Its goals are to achieve a 12% conversion efficiency in single-junction amorphous-silicon solar cells of at least one square centimeter, an 8% conversion efficiency for amorphous-silicon modules of at least 1000 square centimeters, and a strong technical base in multijunction cells leading to 18% conversion efficiency by 1988.

PV Energy Systems' Maycock predicts that amorphous-silicon thin-film solar cells with at least 10% efficiency, a 20-year lifetime, and a cost of $1.50 per watt will be achieved by 1990. Such cells would be economically competitive for central power generation without tax credits. Thin-film solar modules would also weigh much less than crystalline-silicon modules, permitting the use of lighter supporting structures and hence reducing area-related BOS costs.

But Maycock is not convinced that amorphous silicon will necessarily dominate the market. "Since it's easier to get very low costs for amorphous silicon—at least on paper—many people are pinning their hopes on this area, but other technologies are still in the running," he says. Recently, for example, single-crystal silicon cells with an efficiency of 19% have been developed. (See "Efficiency rises for solar cells," p. 10.) Other strong contenders include ribbon-crystal silicon and cast semicrystalline silicon. "I foresee a many-horse race until about 1992, when a clear leader should emerge," Maycock concludes.

Cheap, efficient solar cells could have a major impact on electric-power gener-

Continuous roll of solar cells consists of a thin film of amorphous silicon deposited onto a flexible substrate. (Photo courtesy of Energy Conversion Devices.)

ation in the United States, particularly for intermediate and peak-load power in Sunbelt states where there is summer daytime peaking (due mainly to air conditioning loads). Eventually, with the development of cost-effective systems for storing electricity, PV plants should also be able to make a contribution to base-load power generation.

Solar-thermal plants. A different approach to generating electricity from the sun is to concentrate the thermal energy in sunlight, yielding high temperatures that can convert water to steam to drive electric turbines. To heat a fluid to above 750° F with good efficiency, it is necessary to intensify sunlight by a factor of at least 200. This degree of concentration is possible only with mirrors or lenses that continuously track the sun's position and focus its rays onto fixed points called receivers.

Three types of solar-thermal concentrator systems have potential for bulk electricity generation. The first consists of a large number of sun-tracking parabolic dish mirrors more than 20 feet in diameter, each having at its focal point a thermal receiver through which a high-temperature oil circulates. Once heated, the oil from all the dishes is pumped to a heat exchanger, which produces steam. Georgia Power's project in Shenandoah, a planned community south of Atlanta, comprises 114 parabolic dishes manufactured by Solar Kinetics (Dallas) and produces 400 kilowatts of electricity and process heat for a knitware factory. In addition, DOE has built a single 36-foot-diameter, 25-kilowatt parabolic dish at Rancho Mirage, Cal., and plans to begin construction of 100-kilowatt multiple-dish plants in Osage City, Kans., and Molokai, Hi., in fiscal 1986.

The second type of solar-thermal concentrator is a parabolic trough system. A field of trough-shaped collectors lined with a highly reflective material concentrates sunlight onto linear receiver tubes along the focal lines of the troughs, heating a fluid inside that is then pumped to the point of use. The collectors track the daily movement of the sun along one axis. Luz Engineering (Encino, Cal.) is currently constructing a parabolic trough system near SoCal Edison's Cool Water Generating Station (Daggett, Cal.). Solar energy will heat the oil working fluid to about 590° F, enabling it to convert water to steam. The temperature of the steam will then be boosted to 780° F by a gas-fired superheater, thereby improving the thermodynamic efficiency of the electrical generation process, according to Howard S. Coleman, director of DOE's Solar Thermal Division. The first phase of the project will generate a net output of 13.8 megawatts for sale to the utility; the total plant will have a net capacity of 41 megawatts when it is completed in 1986.

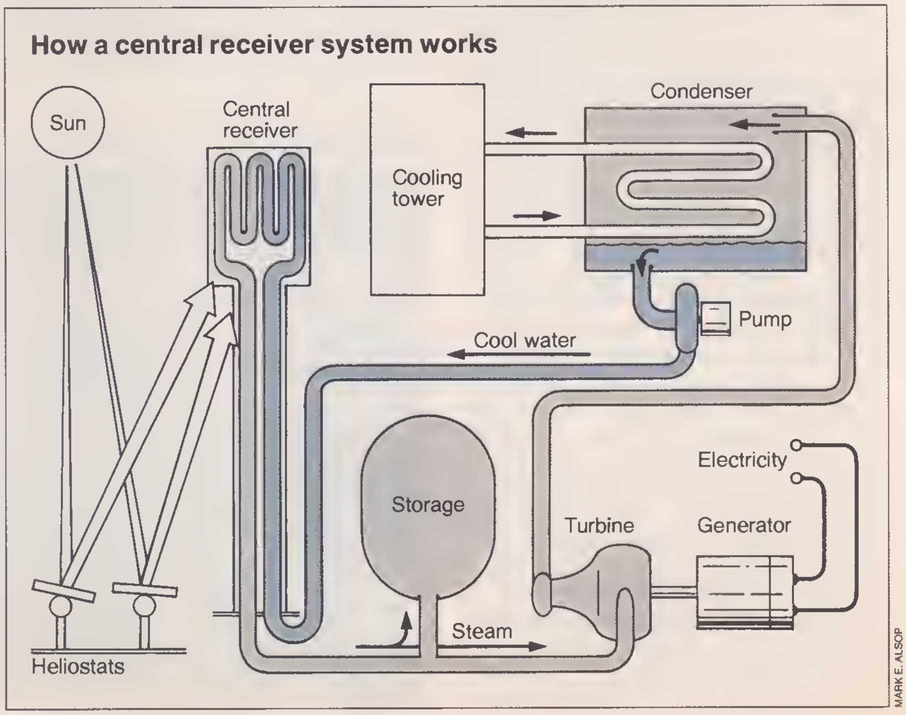
The third solar-thermal design is the central receiver system (CRS), or "power tower." A large receiver structure is positioned atop a high tower, at the focal point of a large array of sun-tracking mirrors called heliostats. These mirrors follow the sun throughout the day and transmit sunlight onto the central receiver; the concentrated thermal energy is then transferred to a working fluid (water, oil, molten salt, or liquid sodium), which generates high-pressure steam for conversion to electricity. "Central receiver systems have the great advantage that heat is transmitted almost entirely as radiation, and consequently the losses are substantially reduced," says Frank Kreith, senior research fellow at SERI.

Because the heliostat array covers about 6000 square meters for each megawatt of thermal energy produced, CRS plants cannot be located in developed areas. But there are large expanses of unused desert land in the Southwest that receive abundant sunlight and would make ideal sites. For example, the first demonstration CRS plant, known as Solar One, was built near the town of Barstow in southern California's Mojave Desert. The plant comprises a circular array of 1818 sun-tracking mirrors, each 430 square feet in area, which beam sunlight onto a central receiver atop a 300-foot tower. Solar One, which went on-line in 1982, produces 10 megawatts of peak electric power for SoCal Edison. Overall conversion efficiencies of better than 25% have been achieved with few maintenance problems.

An advantage of the power tower is that heat transferred to a working fluid is relatively easy to store. Solar One's thermal storage system ranges in capacity from "buffer" storage over short periods, such as cloud passage, to longer-term storage for up to six hours. Although several workers now run the plant, it will eventually be fully automated, requiring only one person to oversee the entire facility.

According to the Battelle Columbus study, CRS technology "ranks high in technical, economic, and institutional feasibility." A CRS plant would take four years to build and would have an operating lifetime of 30 years. But CRS plants are not yet competitive with conventional fuels: The study estimated that a plant starting up in 1990 would produce electricity at a cost 60% higher than that of a conventional coal-fired plant. Solar-thermal plants will therefore be economically viable only in areas with abundant sunlight, large expanses of cheap land, and poor access to fossil fuels.

Central receiver system consists of a large field of sun-tracking mirrors called heliostats, which reflect sunlight onto a receiver mounted on a tower. The concentrated sunlight heats a working fluid (here water), driving a turbine/generator.



Second-generation plants. The cost-effectiveness of CRS plants should improve as second-generation facilities are designed. Because about 60% of a plant's total capital cost comes from the heliostats, an intensive R&D effort is underway to reduce their price and improve efficiency. Kreith and his co-workers at SERI are developing a more accurate sun-tracking mechanism for the heliostats, as well as an inexpensive substitute for costly glass mirrors—a thin membrane of highly reflective plastic or metal stretched over a frame to create a large and optically accurate reflecting surface.

Line-focus parabolic trough system under construction at Daggett, Cal. (Photo courtesy of Luz Engineering.)

Another goal of current research is to improve the efficiency of CRS plants by achieving higher operating temperatures. At Sandia National Laboratories (Albuquerque, N.M.), an experimental CRS plant is using molten salt as the heat-transfer fluid because it can carry more heat per pound than water/steam. In addition, SERI researchers have developed a new design concept in which the concentrated solar radiation impinges directly on a molten-salt working fluid flowing down an inclined plane, instead of transferring heat through a system of pipes.

Two commercial second-generation CRS plants are also in the works. SoCal Edison is negotiating with McDonnell Douglas Astronautics (Huntington Beach, Cal.) for the construction of a 2000-acre, 100-megawatt CRS system called Solar 100. And PG&E is working with Bechtel (San Francisco), Rockwell International's Energy Systems Group (Canoga Park, Cal.), and ARCO Solar on a design for a 30-megawatt power tower with a liquid-sodium working fluid that may eventually be built on the Carrisa Plain with third-party financing, according to Tom Hillesland, a senior electrical engineer at PG&E.

A major drawback of existing CRS plants is that they use water for cooling and for production of steam to drive electric turbines; water is scarce in the desert areas where the plants would operate most economically. Alternatives under study include cooling systems using atmospheric air and closed-cycle conversion systems based on liquid sodium.

Solar ponds. Another promising solar-thermal technology is the salt-gradient solar pond: a shallow body of still water that collects solar radiation and stores it as heat that is then converted to electric power. Unlike other solar generating technologies, solar ponds have inherent thermal storage capacity. Heat trapped by the pond during sunny hours can be utilized 24 hours a day—even during the winter months when there is relatively little sunlight. Thus solar ponds can generate electricity whenever it's needed, not just when the sun is shining. Because electrical transmission is a relatively efficient method for transferring energy, "you can build a solar pond where the necessary resources are, and then transmit the electricity to areas where the power is needed," says Ital Meitlis, senior research engineer at SoCal Edison and manager of the utility's Solar Pond Project.

Although solar pond technology has been studied for 20 years, its application to large-scale energy production has only recently become feasible. The theory behind solar ponds is quite simple. Normally, the convection of water in a pond results in even temperature throughout. But convection can be suppressed by dissolving salt in the pond at concentrations that increase with depth. Since salt water is heavier than fresh water, it forms a dense layer along the bottom of the pond, with the layers of less salty water above acting as insulation to prevent heat loss to the air. As a result, the bottom layer can approach the boiling point.

The thermal energy stored in a solar pond is converted to electricity with a Rankine-cycle heat engine. First, the hot brine is drawn from the bottom of the pond and pumped into an evaporator, where it vaporizes an organic working fluid such as freon, which boils at low temperature. The freon vapor flows under pressure through nozzles to turn an electric turbine, and then travels to a condenser, where cool fresh water from the top layer of the pond or from a separate evaporation pond condenses it back to a liquid. Finally the freon is pumped back to the evaporator, where the cycle begins again.

Construction of an economical solar pond requires inexpensive flatland, ample solar radiation, a supply of cooling water, a low-cost source of salt or brine, and access to utility interconnection. "The major difficulty with an electricity-producing solar pond is that the low temperatures lead to small conversion efficiencies, which makes every little cost significant," says Marshall Alper, manager of the Solar Energy Program at NASA's Jet Propulsion Lab (JPL—Pasadena, Cal.).

Beginning in the late 1970s, SoCal Edison participated in an in-depth study with JPL and DOE on the design for a 600-megawatt solar pond, to be built near the Salton Sea in southern California's Imperial Valley, but the project was cancelled because of insufficient funding. This year, however, SoCal Edison signed a power-purchase agreement with Ormat Systems (Hopkinton, Mass.), an Israeli company that has pioneered the development of large-scale solar ponds for producing electric power. Ormat recently completed its first commercial plant—a 5-megawatt installation near the Dead Sea, covering 60 acres and costing $20 million—and has put together the engineering and financing package for the first solar-pond power plant in the U.S.

According to Hezy Ram, marketing manager for alternative energy systems at Ormat, the company will be building a 48-megawatt solar pond on Danby Dry Lake in southeast California, near the Arizona border. The dry lake bed has a large supply of brine just underground, which will be pumped out and concentrated by evaporation. To prevent the concentrated brine from seeping out of the pond, Ormat has developed a patented liner system consisting of multiple layers of polyethylene sheeting and compacted clay.

SoCal Edison will help with site selection and interconnection to the utility grid, and has agreed to buy electric power from the plant for 30 years. The pond will collect solar radiation throughout the day but will generate electricity only during peak hours (1–7 PM weekdays in the summer, 5–10 PM weekdays in the winter), when the rates paid by the utility are the highest. The

power-purchase contract calls for completion of the first phase of the project—a 12-megawatt solar pond covering about 100 acres—by the end of 1985, with the remaining 36 megawatts to be finished between 1987 and 1989.

Ormat also hopes to build a large solar pond near Utah's Great Salt Lake. Solar ponds require a heat sink—a source of cool water—in order to condense the freon working fluid. Thus, although there is less aggregate solar radiation in Utah because the state has more cloudy and snowy days, the availability of colder water means that the Rankine engines would operate more efficiently. Because of this trade-off, solar ponds can work well at higher latitudes, although the technology is limited by its requirements for cheap land, access to transmission lines, and ample supplies of brine and topping water.

Wind power. Of the radiant energy from the sun that reaches the earth every day, only 2% is converted into wind, yet this fraction still represents a significant quantity. According to a recent study by the Worldwatch Institute (Washington, D.C.), enough wind energy is available in the United States to provide up to 14% of the nation's projected demand for electricity in the year 2000. Like other forms of solar energy, wind power is nonpolluting and renewable.

Wind turbines are of two basic types: horizontal-axis and vertical-axis. Although most wind turbines in current use are of the former type, vertical-axis Darrieus turbines are also appearing on the scene in commercial numbers. These machines, resembling upside-down eggbeaters, consist of two or three curved aluminum blades turning a central upright shaft, which is connected to a ground-based generator. While horizontal-axis turbines have a higher performance efficiency, vertical-axis turbines are easier to maintain and repair because the generator is on the ground. Power-conditioning units convert the direct current produced by wind turbines into alternating current compatible with the utility grid.

Horizontal-axis turbines come in a wide variety of sizes, ranging from small 10-kilowatt turbines to towering 4-megawatt behemoths with a rotor diameter of 256 feet. Because giant turbines have high capital costs and maintenance problems due to severe stresses in high winds, only about half a dozen are in service nationwide. Large turbines have also aroused protests because of their annoying sounds, low-frequency vibrations, and interference with TV reception.

Over the past several years, "wind farms" consisting of large arrays of medium-sized wind turbines have been installed at windy sites (such as mountain passes) to feed power into local utility grids. The electric power generated by wind farms is consumed as soon as it is generated, enabling utilities to conserve fossil fuels. Utilities pay wind-farm companies according to a standard schedule, with rates determined by season and time of day.

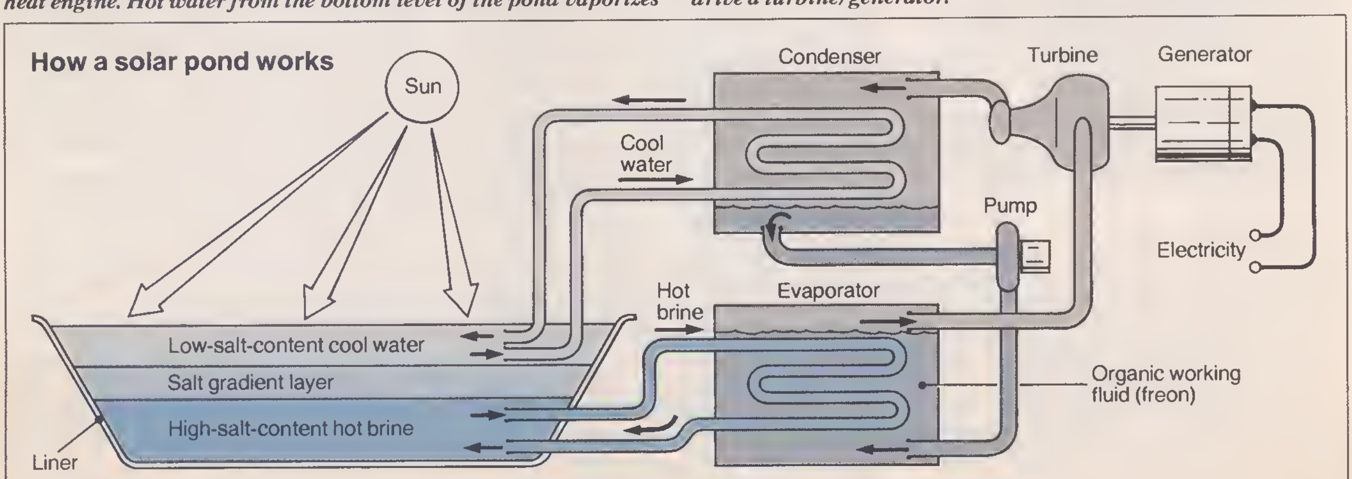
Because wind turbines can be dangerous if they break apart in heavy winds, they must be erected far from housing developments, on land such as steep or rocky terrain otherwise suitable only for livestock grazing. Most wind-farm companies buy or lease a windy site, analyze wind patterns, plan the array, and install machines purchased from a supplier. Some firms manufacture their own turbines, including Fayette (Tracy, Cal.), U.S. Windpower (San Francisco), WindMaster (Sacramento), and Flo-Wind (Kent, Wash.).

While a few scattered wind farms have been installed in several midwestern and western states, the vast majority are in California. By the end of 1983, some 40 wind-farm companies in California had installed more than 4000 wind turbines at favorable sites such as Altamont Pass near Livermore. Current installations statewide have a total generating capacity of over 250 megawatts, enough to meet the electrical needs of about 100,000 households. According to estimates by the California Energy Commission, roughly 4000 megawatts of wind farms—enough to supply 8% of the state's electricity—will be on-line by the year 2000.

Although the wind industry has focused on medium-sized turbines, it has recently begun to scale up to larger machines, mainly in the 100–250-kilowatt range but with a few as large as 500–600 kilowatts. "My feeling is that the industry must learn to walk before it can run," says John Day, president of Strategies Unlimited (Mountain View, Cal.), a renewable-energy consulting firm. "Boeing couldn't build the 747 before it had built the 707. In the same way, we have to learn how to make intermediate-sized turbines before we can scale up to larger ones." Larger turbines are more economical because operating and maintenance costs remain constant while power output increases, although a point of diminishing returns is reached when construction costs begin to escalate. No one is yet sure exactly what the optimal size is, but Day speculates that it may be between 1.5 and 3 megawatts.

Because of improved technology and increased experience, operating and maintenance costs for wind farms are

Thermal energy collected in a solar pond drives a Rankine-cycle heat engine. Hot water from the bottom level of the pond vaporizes an organic working fluid, which then flows under high pressure to drive a turbine/generator.



declining steadily. "Downtime for residential-sized wind systems has gone from 60–70% four or five years ago to less than 10% today," says Tom Gray, executive director of the American Wind Energy Association (AWEA—Alexandria, Va.). "I expect to see similar and probably faster improvement with wind farms. Because the turbines are all located at the same site, it's easier to make improvements and determine quickly whether a problem is generic."

Gray predicts that if the prices of conventional fuels continue to rise at their present slow rates, wind power will reach the competitive range sometime between 1985 and 1990. Still, it will take time for the next generation of cheaper, more durable, and more reliable turbines to be developed and tested. Intensive research is underway on new materials for turbine blades—including glass fibers, graphite fibers, and composites—and on advanced aerodynamic design to reduce system loads. Meanwhile, the wind-turbine industry is lobbying Congress to renew the federal tax credits, which are due to expire at the end of 1985. If the credits are extended long enough to subsidize the next generation of wind turbines, says AWEA's Gray, the wind-power industry should become a viable commercial enterprise.

Solar's potential. It is hard to predict which solar technologies will prove most viable. But as demonstration plants are built, there will be a natural weeding-out process: Those technologies that can make it into the future without tax credits will survive, and those that cannot will fall by the wayside. What seems clear is that many solar technologies that are not competitive at today's prices will become much more so in the future. "Most of the large solar plants now being built are first of a kind," says SoCal Edison's Meitlis. "When you build a pilot plant, you usually find ways of making it cheaper the second time around. So if solar plants are marginally successful now, it's likely that the next generation can be built for 20% or 30% less, making up for the lack of tax credits."

What percentage of the nation's electrical needs will be met by solar power in the year 2000? Estimates range from 2% to more than 20%, a crucial variable being the price of conventional fuels. SMUD's Anderson contends it will be 30 years before there are enough solar plants in operation to make a real difference. But PV Energy Systems' Maycock predicts that by the year 2000 there will be 5000 megawatts of installed photovoltaic modules—the equivalent of five nuclear reactors or coal-fired plants—with annual production on the order of 1000 megawatts. Although photovoltaics would still constitute less than 5% of the nation's generating capacity, PA's Magid notes that manufacturing and connecting 1000 megawatts of photovoltaic capacity would take only a year—a tenth the time needed to build an equivalent-power nuclear plant. Moreover, while conventional plants generate no power until construction is complete, portions of a large PV array can go on-line as they are installed.

Darrieus vertical-axis wind turbine at a test facility in Sandia, N.M. (Photo courtesy of DOE.)

Market penetration by solar technologies will clearly not be uniform across the country. Central-station solar-thermal and PV plants will serve initially to fill peak-load demand in regions of the Sunbelt where sunlight is intense and land prices are relatively low. Large-scale construction of PV plants will probably begin in the mid-1990s, although it may be constrained by the rate at which solar modules can be manufactured.

Before PV arrays can start to provide intermediate and base-load power, however, an inexpensive method will have to be developed for storing surplus electric power generated by solar plants. Batteries for storing electricity are still too costly, but promising technologies include compressed-air storage in deep underground caverns, and pumped-hydro storage, in which surplus electric power generated during the day is used to pump water uphill; at night the water is allowed to flow back down, driving an electrical turbine. PG&E is constructing a pumped-hydro station, but because such systems require large amounts of water and are inefficient and capital-intensive, few will be built in the near future.

In the long run, the most efficient way to store solar-electric power may be in the form of high-energy chemical bonds. One approach is to pass electricity through water, splitting water molecules into hydrogen and oxygen. At night, or when solar systems are not operating at capacity, the stored hydrogen gas can be passed through fuel cells and converted back to electricity. In principle, hydrogen gas produced at large central-station solar plants could be distributed through existing natural-gas pipelines to distant parts of the country where direct solar conversion is less economical. But because hydrogen has a very low density and is highly combustible, it poses major technical problems for storage and safe handling. Other chemical storage concepts include methane gas and an artificial variant of photosynthesis.

Continuing research on solar-electric generation and storage should eventually yield cost-effective solutions. Advocates stress that an intensive investment in solar R&D must be made now if the inevitable transition away from fossil fuels to more sustainable forms of energy is to be smooth. "If you look at the history of technology," says SERI's Kreith, "it takes about 30 years for a new generating system to achieve major market penetration."

Another incentive to develop solar power arises from the increasingly serious problems associated with conventional fuels. "Over the next 50 years, only three categories of energy technology make sense—coal and other solid fossil fuels, fissile nuclear resources, and renewables," says Denis Hayes, former director of SERI and now a consulting professor of civil engineering at Stanford University. "There are intractable problems with fossil fuels because of carbon dioxide, which will become a major global issue. And if we rely on light-water reactors and breeders, we're going to have a huge amount of fissionable isotopes moving through the world's arteries of commerce, which would make the world a pretty unstable place. So that means we've got to put intensive effort into developing more elegant renewable technologies, so that we'll have a wider array of options to choose from." □

Jonathan B. Tucker is a senior editor of HIGH TECHNOLOGY.

For further information see **BUSINESS OUTLOOK** *on next page and* **RESOURCES** *on page 78.*

BUSINESS OUTLOOK

Wind, photovoltaics lead renewable market

Wind and photovoltaics are receiving the bulk of the attention in the market for renewable energy sources because they come closest to generating electricity as cheaply as conventional fuels. They are, however, still far from being cost-competitive. While coal and nuclear fuels produce power at about 4¢ per kilowatt-hour, power costs twice that amount with wind and eight times as much with photovoltaics.

But wind and photovoltaics are expected to come down in price through the decade as more power plants based on those technologies are built and suppliers realize economies of large-scale production. Two photovoltaic plants and at least 60 "wind farms" are now in operation in the U.S., and more of each are in the works. Sales of wind hardware, worth $290 million last year, are increasing 140% annually and should be worth $410 million by the end of '84, according to John Day, president of the market research firm Strategies Unlimited (Mountain View, Cal.). While photovoltaic hardware sales were less than $170 million in '83, Paul Maycock, president of the consulting firm Photovoltaic Energy Systems (Alexandria, Va.), projects sales will top $210 million this year.

As plant construction continues and advances are made in technologies, the cost of electricity from wind should approach that of electricity from conventional fuels as early as 1990, according to a study by the energy economics group at Battelle Columbus Laboratories (Columbus, Ohio). Photovoltaics is not expected to be as cost-competitive until at least the mid-'90s, notes William Huss, a principal research scientist at Battelle. Huss qualifies those projections, however, by saying that they depend on whether the market develops at its current rate. If plant construction falls off, costs may take longer to come down.

Federal and state tax incentives are now enticing individual and corporate investors to build wind- and photovoltaic-based power plants. Most of those plants are operating in California, where the state provides a generous 25% energy tax credit on top of the federal government's 15% credit. The credits, however, will soon expire; California's credits run out at the end of '86, and the federal government's at the end of '85. New legislation would be required to extend them.

While analysts are generally confident that suppliers will be able to lower costs enough for wind to be economically feasible by the time the credits expire, they express doubt that the same will hold true for photovoltaics. "Wind power has been around for a long time, and it's already close to being cost-competitive," notes Edward Dickson, a senior analyst with Strategies Unlimited. He adds that the only strides yet to be made in the market are in extending the lifetimes of wind turbines, thus allowing power-plant owners to spread capital equipment cost over longer periods.

Photovoltaic suppliers have a harder row to hoe. More research is required in order to increase the efficiencies by which photovoltaic cells extract electricity from the sun, and manufacturers must substantially reduce cell production costs. Earnings derived from hardware sales to power-plant operators are now helping to fund that research, but those earnings are in jeopardy.

"Photovoltaic hardware suppliers are already using some pretty creative accounting procedures to entice third parties to invest in power plants," says Robert Johnson, of Strategies Unlimited. "Without the credits, I'm not so sure they'll be able to attract support."

In lieu of government incentives, vendors may have to finance plants themselves or turn to markets other than electric utilities. Johnson notes that photovoltaic systems are economical in remote telecommunications applications and as central sources of power for small villages in third-world nations. While these applications are much smaller than the bulk utility market, he says they will enable suppliers to clear inventories, move down the learning curve, and cut production expenses.

The market for wind hardware is controlled primarily by small firms such as Fayette (Tracy, Cal.), U.S. Windpower (San Francisco), ESI (Littleton, Colo.), Enertech (Norwich, Vt.), and Flo-Wind (Kent, Wash.). Foreign competitors include the Netherlands' Polemko, Belgium's HMZ, and three Danish firms: Vestas, Nordtank, and Wind Matic.

"By allowing suppliers to underwrite their massive R&D costs, tax credits are playing a key role in driving developments within the photovoltaics industry. Our future tax policy will determine how quickly this market shapes up."

John Corsi
President
Solarex

The majority of the entrepreneurial ventures that pioneered the photovoltaics hardware market either were forced to drop out of the business or were acquired by large diversified oil companies. Most of the independents that managed to survive are financing their activities through joint ventures with oil interests. "The research and development costs associated with photovoltaics are prohibitive to small suppliers," notes Strategies Unlimited's Day. "But oil companies can afford to look to the future at the expense of short-term profits." Among the participants in the market are Atlantic Richfield's ARCO Solar Div. (Woodland Hills, Cal.), Standard Oil of Indiana's Solarex subsidiary (Rockville, Md.), and Mobil Oil's Mobil Solar Energy (Waltham, Mass.). Smaller firms include Solavolt (Phoenix), in partnership with Shell, and Energy Conversion Devices (Troy, Mich.), in partnership with Standard Oil of Ohio.—***F.J.C.***

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INDUSTRY STEPS

No longer a black art, catalyst science provides formulations with improved yields, higher efficiencies, lower costs, and greater selectivity

◆

by Thomas H. Maugh II

After years of modest growth, the search for new industrial catalysts has suddenly picked up steam. Behind the trend are some potent driving forces: the need for new sources of energy and chemicals, the desire for new products, and the potential scarcity of metal catalysts such as platinum, palladium, and rhodium (called noble metals because of their corrosion-resistance). At the same time, catalyst research, once rather arcane, is being put on a more rational footing.

Perhaps the most striking development in catalysis over the past decade is the wealth of new knowledge about the behavior of molecules on catalyst surfaces. These discoveries, made possible by a powerful new generation of computers and analytical instruments, may soon pay off handsomely in the form of new catalysts that are tailor-made for specific functions, provide high yields, and are based on less costly metals.

The importance of catalysts can hardly be exaggerated. They are involved in the manufacture of nearly every chemical used in industry, every synthetic fiber found in clothes, and every detergent used to clean them. The catalytic production of ammonia (used in fertilizers) makes possible the high yields of modern agriculture. In fact, a strong case could be made that modern society would be unable to exist without catalysts.

Most catalysts—defined as compounds that effect chemical changes without themselves being changed—consist of metal particles deposited on solid supports made of such materials as alumina or silica. (Many metals are used, including iron, nickel, platinum, and palladium.) When chemical reactants are passed over these formulations, they are converted into myriads of useful products.

Exactly how these transformations occur is not completely known, but the adsorption (adherence) of reactant mol-

UP QUEST FOR CATALYSTS

ecules onto metal surfaces to form temporary bonds with the metals seems to be a vital step. Apparently the bonds to the metal weaken internal reactant bonds, leaving them susceptible to rupture and rearrangements.

While some researchers are filling in the gaps in their knowledge of the molecular behavior of catalysts, others are readying whole new classes of catalysts. These are some key areas under development:

◆ Shape-selective systems, which allow molecules of only certain sizes and shapes to be produced, boosting yields of wanted products while cutting down on unwanted byproducts. Catalysts based on natural and synthetic minerals called zeolites, particularly Mobil's system for converting methanol to gasoline, are the best-known examples.

◆ Cluster catalysts, consisting of small numbers of interconnected metal atoms and attached side groups. Their molecular structures permit great selectivity in favor of one or two products. They may also allow cheaper metals such as nickel to be used in place of costly metals such as chromium.

◆ Homogeneous systems, in which both catalysts and reactants are in solution. They not only offer great selectivity but cut down on materials used in catalysts. Several homogeneous catalysts offer attractive new routes to synthetic rubber and fiber intermediates.

◆ Chiral catalysts, which are optically active (they rotate a beam of polarized light to the right or left instead of letting it pass unimpeded as do most other molecules). Such catalysts allow selective syntheses of compounds that are also chiral; many of these are valuable hormones or drugs.

◆ Photocatalysts. These are compounds that use sunlight or some other light source to generate electricity or split out valuable hydrogen from water. These catalysts may eventually help get rid of sulfur dioxide emitted from power plants by employing the noxious gas in hydrogen-from-water processes.

Whatever the ultimate benefits of these new varieties, present catalysts are already a thriving venture for chemical makers. Worldwide sales last year topped $1.6 billion. But this is just the tip of the iceberg. The total value of products made with the aid of catalysts in 1983 was $300–500 billion, according to Vladimir Haensel of the Univ. of Massachusetts.

Despite the economic importance of catalysts, there has been little scientific knowledge about how they actually work. But this is changing. The computer, for example, now allows researchers to create a theoretical model of the electron distributions of simple molecules—those in synthetic gas (or syngas), for instance—during reaction. This is leading to a new understanding of what actually happens during catalysis—the first step toward being able to predict the course of new reactions.

ARMEN KOJOYIAN

In the meantime, microprocessor-controlled operation and data gathering have led to an alphabet soup of instruments—with names like LEED, AES, HREELS, ESCA, SIMS, EXAFS, and TDS—for studying catalyst surfaces. More than 80 analytical techniques are in use. Most involve bombarding catalysts with light, atoms, electrons, or neutrons and analyzing resultant emissions of energy or particles. Such emissions give clues to the nature of catalyst surfaces and intermediate states.

Nowhere are these tools coming in handier than in the study of heterogeneous catalysts—systems in which reactions in solution occur on the surface of solid metals, metal oxides, or minerals such as silica or alumina. Some 90% of chemical products are made with the help of heterogeneous catalysts.

New insights may open the door to custom-made catalysts. For instance, it may soon be possible to use advanced spectroscopic techniques "to look at a surface and tell if it will be a good catalyst," says David Hercules of the Univ. of Pittsburgh. It may also soon be feasible to alter surfaces in a predictable way. "We can begin to think about using [specially introduced] impurities to tailor catalysts for specific purposes," says D. Wayne Goodman of Sandia National Laboratories (Albuquerque, N.M.).

Shape-selective systems. The revolution in research techniques isn't the only significant trend in industrial catalysts. Equally important is the proliferation of new classes of catalysts, of which one of the most intensively studied is shape-selective systems. First discovered about 20 years ago by Paul B. Weisz at Mobil Oil (New York), these catalysts are based on the use of porous materials—referred to generically as molecular sieves—containing microscopic cavities of known size. Many different materials have been used as molecular sieves, but the most important is a family of aluminosilicate zeolites.

Shape-selective catalysts were developed to remedy one of the principal drawbacks of other heterogeneous systems: their lack of selectivity. In such industrial reactions as the Fischer-Tropsch process (the reaction of synthesis gas—a mixture of carbon monoxide and hydrogen—to yield hydrocarbons and oxygenated organics) and catalytic reforming (transforming hydrocarbon fuels into products of higher octane rating), a wide spectrum of products is generated. But for most applications—production of high-octane gasoline, for example—a narrow product range is desirable.

One way to achieve this narrowed distribution is to place a catalyst made of a noble metal (platinum, palladium, ruthenium, or rhodium) inside the cavities of the zeolite. The dimensions of the

What's an industrial catalyst?

Catalysts have been inextricably linked to industry since 1835, when the Swedish chemist Jons Jakob Berzelius first coined the term to describe materials that facilitate reactions without themselves being consumed. By the turn of the century, it was known that catalysts exert their effects by changing only the *rate* of a reaction. In other words, catalysts cannot force a reaction to occur if it is not predestined chemically.

Perhaps even more important than catalysts' ability to increase reaction rates is their tendency to alter rates selectively so that a desired reaction is favored over competing reactions. When crude petroleum is heated, for example, large molecules are broken down into a great number of smaller ones, a process known as cracking. But when a catalyst is used in the cracking process, the slate of products is sharply reduced to a few desirable ones.

The era of large-scale catalysis began in 1904 with German chemist Fritz Haber's catalytic synthesis of ammonia. This process, in which atmospheric nitrogen is passed over a bed of iron particles, is still used in virtually the same form today.

Catalyst use picked up dramatically during World War II when cracking of petroleum became necessary to produce high-octane fuel for high-compression engines. The trend continued after the war with the introduction of catalytic reforming, which converts linear hydrocarbons into cyclic benzene-type hydrocarbons called aromatics, in order to increase octane. Another postwar growth area was the use of catalysts to produce polymers such as plastics and synthetic rubber. Catalysts got another boost in the late 1970s when automobile manufacturers began installing catalytic converters on cars to control emissions.

Today the petroleum industry is the largest user of catalysts. In 1983 it used an estimated 4.5 billion pounds, worth $530 million. The chemical industry in the same year used about 210 million pounds of catalysts, worth about $485 million; and the auto industry used $325 million worth in emission control. In addition, the chemical, pharmaceutical, detergent, and food industries used about $200 million worth of enzyme catalysts. Overall, catalyst use is increasing by about 3.5% a year.

Industrial catalytic reactions are usually carried out in either batch or continuous reactors. Batch reactors are charged with reactants, solvent, and catalyst, and sealed until the reaction is completed, whereupon the desired products are separated from the rest of the mixture. In continuous reactors a steady stream of reactants is introduced at one end and passes over a catalyst (often a metal deposited on an inert support such as alumina or silica gel). The products are continuously withdrawn and purified at the other end. The supports in these reactors not only provide a large surface area on which reactions can take place but also prevent coalescence of catalyst particles, which would hinder activity. Heating, cooling, or pressurization is sometimes necessary in both types of reactors.

Many varieties of catalyst are used, although most are metals or metal-containing compounds. In the hydrogenation of olefins (hydrocarbons with double bonds), for example, metals such as platinum, palladium, rhodium, and nickel are employed. The widely used Ziegler catalyst, which converts ethylene into polyethylene, consists of a titanium compound such as titanium dichloride and an aluminum compound such as triethylaluminum. Ammonia synthesis uses an iron-based catalyst. And a vanadium pentoxide catalyst on a silica support helps the hydrocarbon naphthalene react with oxygen to form phthalic anhydride, a key synthetic fiber intermediate.

Most catalysts have "active" surfaces, which can form temporary bonds with reactant molecules. Typically these molecules must be adsorbed (must adhere) onto a catalyst surface for reactions to occur. The rates of catalytic reactions depend primarily on the relative rates of adsorption of reactants and desorption (release) of products.

Many catalysts lose their potency after a while. In some cases they can be regenerated by simple heating to drive away films or deposits on their surfaces. In other cases, however, chemical "poisons" react more or less permanently with the active surfaces of catalysts, blocking further activity. When this happens, the catalyst must be replaced.

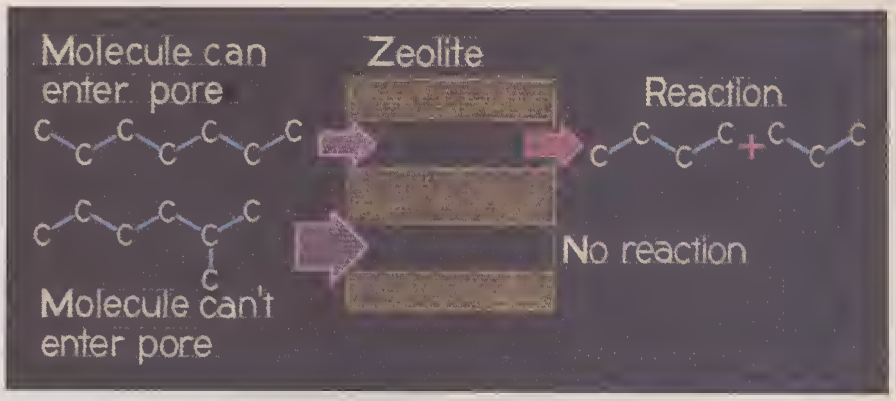
cavity then control molecular sizes or limit the range of products in catalytic reforming.

Zeolites are particularly valuable for converting linear hydrocarbons into branched ones that have much higher octane ratings: Linear hydrocarbons readily fit into the cavities, where they are catalytically rearranged into branched compounds. But the cavities constrain the growth of these branched hydrocarbons to the desired size. The zeolite itself has many chemically acidic sites that aid in catalytic reactions, particularly the rearrangement of hydrocarbon side chains.

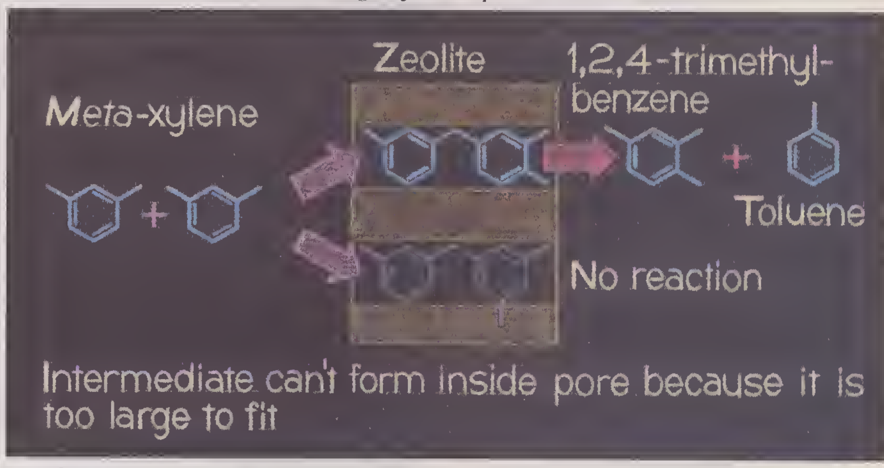
Perhaps the most important new use of zeolites is a process developed at Mobil for the conversion of methanol (derived from coal or other fossil fuels) into gasoline. The process occurs in two stages. In the first, methanol is passed over a heterogeneous catalyst, consisting of either nickel or cobalt mixed with thorium oxide, to produce a mixture of hydrocarbons; the hydrocarbons are then passed through a proprietary zeolite, dubbed ZMS-5, that converts them to gasoline. As much as 86% of the feed can be converted into gasoline, calculated on the basis of the methanol's carbon content. On a weight basis, however, as much as 56% of the product is water.

The first commercial application of the Mobil methanol-to-gasoline process will take place at a plant in New Zealand. Beginning in 1985, the plant will convert 140 million cubic feet of natural gas per day into about 14,000 barrels of motor fuel. Meanwhile, Union Carbide Corp. (Danbury, Conn.) announced last year that it had developed its own zeolite-based methanol-to-gasoline process. Methods like Mobil's or Carbide's might eventually prove valuable for producing gasoline from alcohol derived from the fermentation of biomass.

Metal clusters. Zeolites aren't the only way to increase selectivity. An alternate approach is to reduce the size of the catalyst from the conventional crystallites (microcrystals) to a well-defined cluster consisting of anywhere from two or three to a dozen or more metal atoms. This is desirable because different sites on catalyst surfaces—crystal facets, edges, terraces, defects, and adatoms (atoms projecting from a plane)—may yield different products. For instance, in the Fischer-Tropsch process, methane might be formed only by edge atoms, cyclohexane might be produced at a site near a terrace, butane at a site with four adjacent atoms, and so forth. If the size of the cystallite could be reduced, however, the number of competing reactions might also be reduced. "In principle," says Geoffrey A. Ozin of the Univ. of Toronto, "if you



Some reactant molecules are too big to fit into pores and thus never react.



DIAGRAMS BY MARK E. ALSOP

In other cases reactants fit into pores but attempt to yield intermediates that cannot fit (bottom). In such cases, further reaction is thwarted. When intermediates fit within pores, however, products are readily formed (top).

have only one size and shape of cluster, you could get only one product."

Small clusters have other advantages. An obvious one is that they minimize the use of expensive metals. Another is that clusters of a few metal atoms differ from bulk metals in their electronic properties; thus they might have unusual catalytic activity.

Until recently, work on clusters had been stymied by the difficulty of producing the molecules and by inadequate instruments for studying them. But the situation is changing with recent advances in instrumentation and the development of two new approaches to making the clusters.

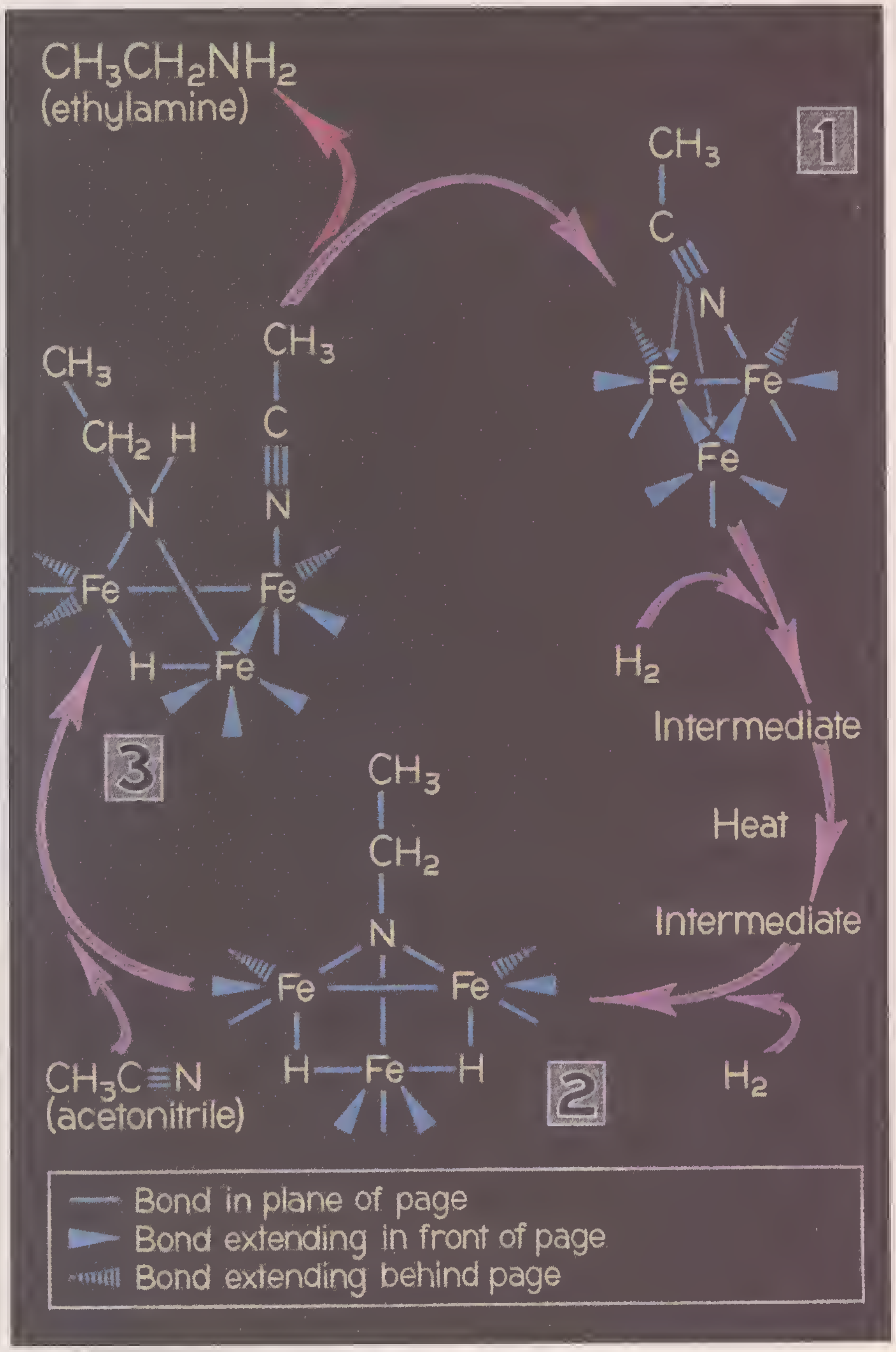
One method, developed by Richard Smalley of Rice University (Houston) and Andrew Kaldor and his colleagues at Exxon Research and Engineering (Linden, N.J.), uses pulsed lasers to vaporize a metal target in the throat of a supersonic expansion nozzle. In such a nozzle, the resulting stream of particles is passed through a cylindrical device. The vapor, exiting the nozzle at supersonic speed and high pressure, expands suddenly, cooling to as low as 2° Kelvin (near absolute zero) and forming metal clusters of two to 200 atoms.

Ozin and Martin Moscovitz of the Univ. of Toronto have used the nucleation of metal atoms at very low temperatures to produce small clusters. In this method, gaseous metal atoms are mixed with relatively large amounts of inert gases and cooled to about 10–20° Kelvin. The metal atoms are then entrapped in a growing film of inert gas, either singly or in very small clusters.

Although research is focusing mostly on the molecular structures of cluster compounds, some important industrial applications may emerge from the work. For example, Ozin has produced catalysts consisting of cluster compounds inside zeolites. In one experiment with such a system, involving the reaction of carbon monoxide and hydrogen, the product contained 85% of one type of molecule (butenes), an "extraordinary" selectivity, says Ozin, that would have been impossible in the past.

Moscovitz has also produced some unique catalysts in a new way. Instead of using the cavities of zeolites to contain the metal catalysts, he has used the tiny pores in an aluminum oxide coating that forms on the outside of an aluminum anode in an electrochemical cell. When metal atoms are deposited onto the aluminum oxide, they form small clusters whose size is constrained by the size of the pores. An iron catalyst produced in this fashion gave much

A cluster compound (1) consisting of three mutually bonded iron atoms can initiate a cyclic process that converts nitriles (compounds with a CN group) into valuable intermediates called amines (compounds with an NH_2 group). One of the iron atoms is attached to the nitrogen of an acetonitrile (CH_3CN) molecule's triple bond, while the electrons in the triple bond form loose ties with the other iron atoms. Addition of hydrogen, along with heating, forms (2); in (2) the nitrogen is now bound to all three irons, and the carbon of the triple bond is hydrogenated to CH_2. Exposure of (2) to acetonitrile results in a molecular rearrangement to (3). Then (3) expels a molecule of ethylamine ($CH_3CH_2NH_2$), regenerating (1).



higher overall yields in the carbon monoxide and hydrogen reaction than yields achieved by Ozin, although product selectivities were lower.

Moscovitz has also used his technique to prepare a nickel cluster catalyst. This catalyst reduces (adds electrons to) unwanted nitrogen oxide pollutants in the presence of either hydrogen or methane as fast as far more expensive platinum and 20 times as fast as commercial nickel catalysts. It thus has the potential to replace precious metals in automobile catalytic converters.

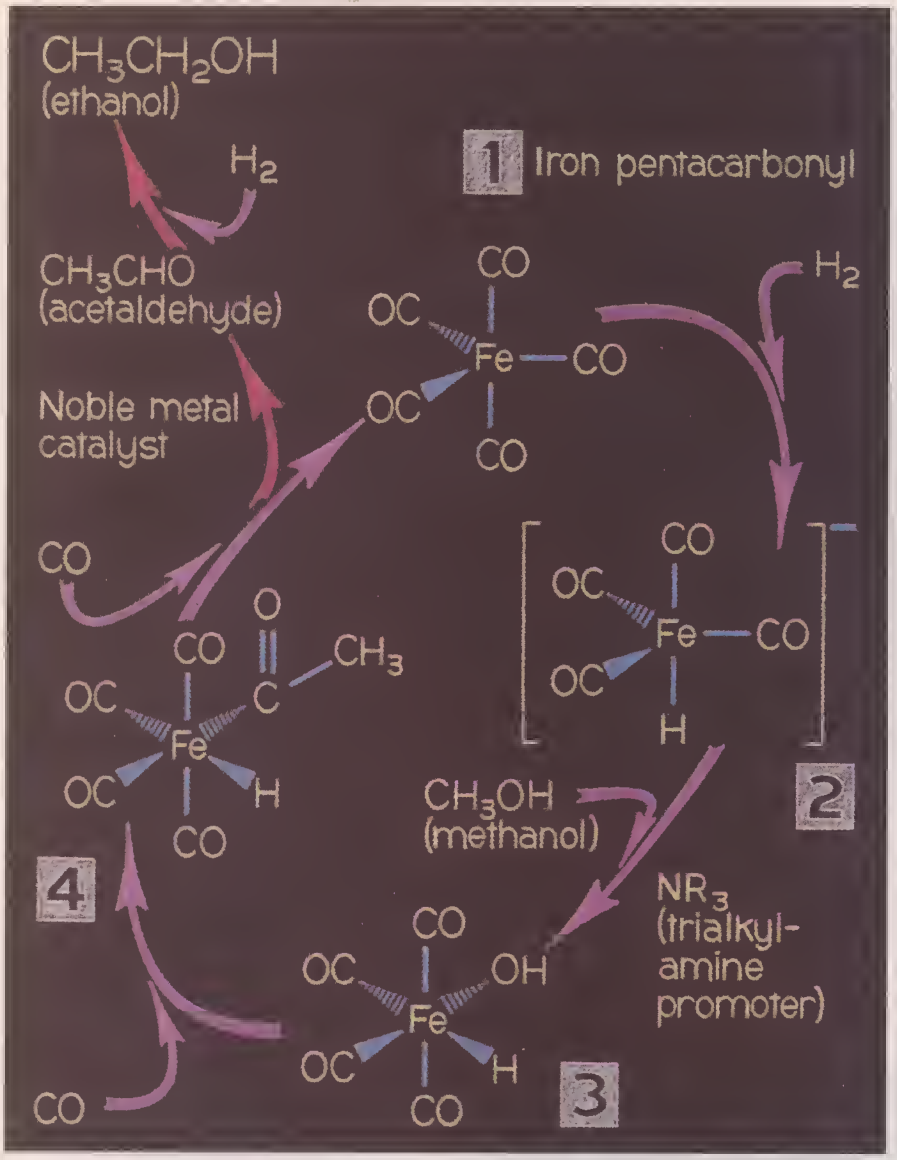
All the catalysts Moscovitz has prepared can dissipate heat (they are in close contact with the aluminum backing, which acts as a heat sink). Hence he predicts that they may be useful for many heat-producing industrial reactions such as the oxidation of ethylene and the production of synthetic intermediates called anhydrides. Such processes now require costly heat exchangers as well as catalysts.

Homogeneous systems. If small metal clusters give greater catalytic selectivity than metal crystals, then the ultimate selectivity might be attainable with molecules containing only one or two metal atoms. Such molecules are typically found in homogeneous catalyst systems, in which both the reactants and the catalyst are dissolved in solution. Most of the homogeneous catalysts being developed today are based on transition metals such as cobalt, iron, manganese, and nickel.

In many instances, homogeneous systems have delivered on their expected high selectivity; their use in industry has thus grown rapidly in the last ten years. Shell Oil (Houston) uses a proprietary nickel complex to convert ethylene to a class of chemicals called alpha olefins. Monsanto (St. Louis) uses rhodium trichloride ($RhCl_3$) and negatively charged iodide ion to produce the key industrial intermediate acetic acid from methanol and carbon monoxide. And Union Carbide uses a proprietary rhodium complex in its "oxo" process for converting olefins into aldehydes. For example, the olefin propylene is transformed into *n*-butyraldehyde, a major source of four-carbon building blocks in the chemical industry. The newest industrial homogeneous process, at Eastman Chemical Products' plant in Kingsport, Tenn., converts synthesis gas into acetic anhydride, an important industrial intermediate.

Meanwhile, several other homogeneous processes for industry are under development. For example, Albert S. C. Chan and his colleagues at Monsanto have developed a process that uses anionic (negatively charged) rhodium catalysts to convert syngas into ethylene glycol—used in antifreeze and as a building block for other chemicals. Monsanto also has a homogeneous process for converting linear olefins into branched dienes (olefins with two double bonds). Dienes of this type can be polymerized to form synthetic rubber.

Two researchers at Argonne National Laboratory (Argonne, Ill.) have developed a new homogeneous method for producing ethanol from methanol. The conventional catalyst is a cobalt complex that leaves water as a byproduct. This water must be separated from the ethanol by distillation, an energy-intensive process. But scientists Jerome W. Rathke and Michael J. Chen use a ho-



In this homogeneous process, hydrogen is added to (1) to form a negatively charged intermediate (2), which reacts with methanol and a "promoter" known as a trialkylamine to yield another intermediate (3) containing a methyl group (CH_3) bonded to the iron. Carbon monoxide (CO) inserts itself between the iron and the methyl group of (3) to form a compound (4) with an acetyl group ($C{=}OCH_3$) attached to the iron. Addition of carbon monoxide to (4) causes expulsion of a hydrogen atom and the acetyl group, forming acetaldehyde (CH_3CHO) and regenerating (1). Meanwhile, the acetaldehyde, with the addition of H_2 in the presence of a noble metal catalyst, forms ethanol.

mogeneous iron-based catalyst, combined with promoters called trialkylamines, to produce ethanol and carbon dioxide. The latter is easily removed from the liquid ethanol without additional energy. Rathke and Chen have also devised a homogeneous method of making methanol from syngas.

Despite their obvious advantages, homogeneous processes have drawbacks. The reactions must often be run at high pressures to keep the catalysts in solution. It is often difficult, moreover, to separate the catalyst from the product. The problem of isolating the catalyst may eventually be solved by techniques that would attach the metal complex to a solid support so that the complex could not go into solution; no such methods are yet in commercial use. Whatever the disadvantages of homogeneous catalysis, they appear to be outweighed by the increased selectivity of the reactions.

Chiral synthesis. The enhanced selectivity shown by the cluster and homogeneous systems can be taken a step further with chiral catalysts. The word *chiral* (pronounced KY-ral) means "handed"—referring to the fact that such molecules come in two different forms, or isomers, whose asymmetric structures mirror each other like right and left hands. In the course of reactions, these catalysts favor one or the other isomer of a pair of product molecules that are likewise chiral.

The mirror-image isomers are not superimposable. If structural models of each isomer are placed on top of each other in an attempt to get corresponding atoms to coincide, there will always be two or more atoms that don't match.

A chiral isomer is called either D or L, depending on its structure. The D and L forms have identical physical properties, but are distinguished by their behavior toward a beam of polarized light. One isomer (it could be either D or L), designated (+), rotates the beam to the right; its counterpart, designated (−), rotates the light the same amount, but to the left.

Many important medicinal chemicals—vitamins, hormones, and antibiotics, for instance—occur in nature as either D or L isomers. Industrial synthesis of these compounds in the past has often been difficult because the reactions produce an equal mixture of the D and L forms. It has then been necessary to separate the desired isomer from the mixture by an expensive and time-consuming process. Chiral catalysts, however, offer the chance to obtain the pure D or L form (or its precursor) directly.

Interest in chiral compounds has grown, says Barry M. Trost of the Univ. of Wisconsin (Madison), because "the demand for ready access to complex organic molecules has increased markedly." Chiral syntheses have enabled scientists to vary the structures of complex natural products systematically. With the beta-lactam antibiotics (related to penicillin), this approach has led to improved therapeutic function (HIGH TECHNOLOGY, Dec. 1983, p. 61).

Chiral catalysts essentially mimic the activity of natural enzymes, which also catalyze reactions selectively in favor of D or L isomers. But for at least two types of chiral synthesis—hydrogenation and epoxidation (addition of oxygen to an olefin)—"we can do better than enzymes," says K. Barry Sharpless of MIT.

The first examples of chiral hydrogenations were reported independently in 1968 by William S. Knowles and his associates at the Monsanto Co. and by L. Horner at the Univ. of Mainz in West Germany. They found that chiral catalysts containing a rhodium atom linked to phosphorus-containing compounds known as phosphines could reduce symmetric compounds called alpha-amino acrylic acids to asymmetric amino acids, the building blocks of proteins. The researchers discovered that the phosphine groups control the directions from which reactant molecules can approach the rhodium atoms, thereby influencing the three-dimensional struc-

What happens on a catalyst surface?

The nature of catalyst surfaces was once mainly the stuff of obscure scientific inquiry. But the question has assumed vital commercial importance. The main reason: If researchers know what happens on catalyst surfaces during reactions, they may be able to modify these surfaces to improve selectivity.

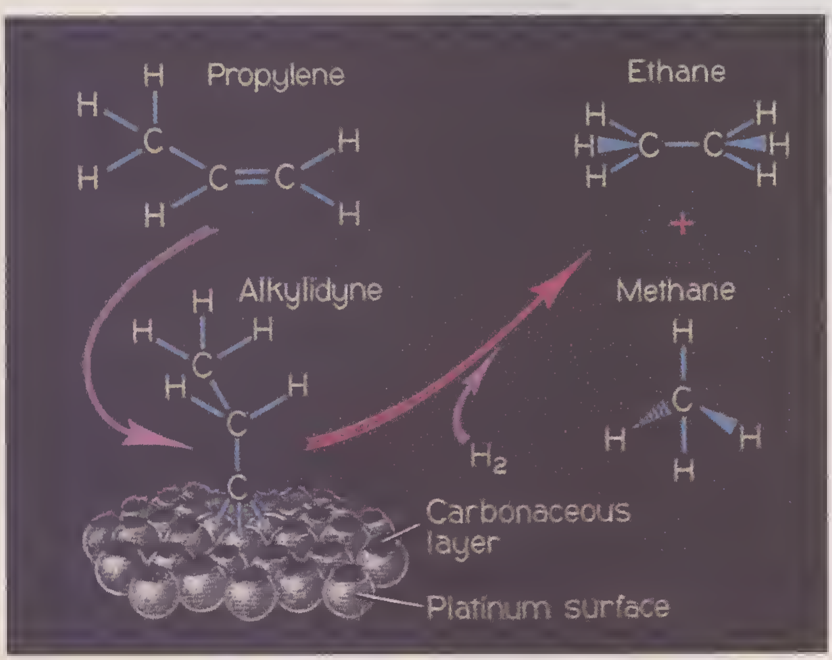
Catalytic surface phenomena have been studied in some model catalyst/reactant systems. One of the most illuminating is the hydrogenolysis of olefins over single crystals of platinum. (Hydrogenolysis is the splitting of a hydrocarbon in the presence of hydrogen; olefins are hydrocarbons with a double bond.) Using a battery of instrumental techniques, physical chemist Gabor A. Somorjai of Lawrence Berkeley Laboratory (Berkeley, Cal.) has traced the sequence of events in a typical hydrogenolysis.

As the reaction gets underway, Somorjai reports, a layer of olefins is adsorbed on the surface of the platinum while the end carbons of the olefins form triple bonds with the metal atoms, creating intermediates called alkylidynes. Simultaneously, the olefins' double bonds start to weaken.

At a reaction temperature of 100° C (212° F) or more, some of the alkylidyne intermediates eject hydrogen atoms to form a carbonaceous layer (mostly carbon but with some hydrogen) on the catalyst surface. This layer, which seems to be essential for catalytic activity, does not cover the entire platinum surface; islands of bare metal are left exposed.

Only some of the alkylidyne molecules form the carbonaceous layer. Most react with hydrogen on the bare metal islands to form a variety of other intermediates. These intermediates are tightly bound to the platinum but are mobile enough to diffuse gradually into the carbonaceous layer around the metal. In this layer the intermediates are less tightly held and can desorb (be released) readily. The carbonaceous layer also aids the reaction by storing large volumes of the reacting hydrogen. The products desorbed from the catalyst surface are alkanes—fully hydrogenated hydrocarbons.

The number and size of the bare metal islands can be controlled by manipulating both the pressure of hydrogen and the concentration of additives such as sodium and potassium. Certain agents such as gold and tin, which can form alloys with the platinum, also increase the activity of the platinum catalyst and change its specificity (orientation toward particular reaction products). They do this not only by altering the concentration of bare metal islands but also by slowing the degradation of the carbonaceous layer into a layer of catalyst-poisoning graphite.



The olefin (propylene) forms an intermediate called an alkylidyne, which is bonded to platinum atoms on the catalyst surface and reacts with hydrogen to form ethane and methane. Surrounding the bare metal atoms in the center are other atoms covered with a carbonaceous layer. This layer stores hydrogen that participates in the reaction and facilitates release of final products.

tures of the final products.

The best current example of commercial chiral synthesis is Monsanto's hydrogenation of a particular alpha-amino acrylic acid to produce L-dopa, a drug used in the treatment of Parkinson's disease. More than 98% of the product is L-dopa. This accomplishment, says Bruce C. Gates of the Univ. of Delaware's Center for Catalytic Science and Technology, probably represents industry's "most sophisticated design of a technological catalyst." Similar processes are being contemplated for production of other L-amino acids.

As for chiral epoxidations, the first example was reported in 1980 by MIT's Sharpless and Tsutomu Katsuki, both of whom were then at Stanford University. The reaction they worked on involves the addition of an oxygen atom to an olefin to form a three-membered ring of two carbons and an oxygen. This ring (an epoxide) can subsequently be opened stereospecifically (in favor of one mirror-image isomer or the other) to produce complex alcohols and related compounds, including some key pharmaceutical ingredients.

Sharpless and Katsuki obtained a chiral epoxide yield of more than 95% with a relatively simple system containing titanium tetraisopropoxide as the catalyst and *tert*-butyl hydroperoxide as the source of oxygen.

Chiral epoxidation has come in handy for the synthesis of (+)-disparlure, the gypsy moth sex attractant used to control the pest. The use of (+)-disparlure agitates male moths and disrupts mating, thereby reducing the moth population; (−)-disparlure not only has no effect on mating but interferes with the activity of its mirror-image counterpart.

In 1980, (+)-disparlure, obtained by separating it from an equal mixture of the two isomers, cost about $2000 per gram. The same substance, now made by the chiral epoxidation process, is available for about $250 per gram; it is used in consumers' gypsy moth traps as well as in government pest-control programs. Chiral epoxidation is currently being introduced into other commercial syntheses, whose identity is in most cases still confidential.

Photocatalysts. Many of the new industrial catalysts require the input of energy such as heat or high pressure. One group of catalysts, now under development in laboratories around the world, requires another form of energy: light. These so-called photocatalysts are not usually thought of in the same context as other industrial catalysts. But they may eventually help produce electricity to power industrial processes; they may also generate

hydrogen that can be burned for fuel or used to convert coal into gaseous or liquid fuels or into chemicals.

The earliest photocatalysts were the photovoltaics such as the common solar cell. But most photovoltaics are made of expensive materials like single crystals of silicon, gallium arsenide, or other semiconductors. In attempts to harness photocatalysts for industrial use, many investigators are trying to obviate the need for single crystals. They are doing this by constructing photoelectrochemical cells, in which photocatalyst electrodes are placed in an electrolyte (a liquid containing dissolved salts).

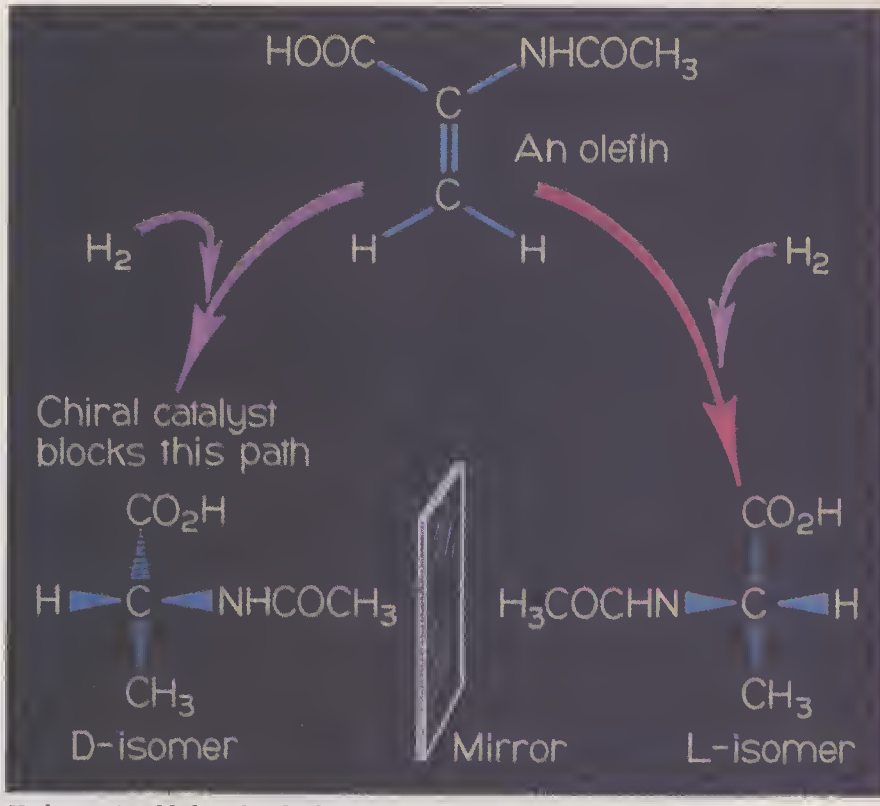
At least one of the electrodes in such a cell contains a relatively low-cost polycrystalline semiconductor. Two types of semiconductors are used, either alone or in combination: a *p*-type, which has a deficit of electrons, and an *n*-type, which has an excess of electrons.

In a photoelectrochemical cell, sunlight pries electrons loose from the *n*-type electrode (the anode) and sends them, via an external circuit, to the cathode on the other side of the cell. (The cathode can be either a *p*-type semiconductor or an ordinary conductive metal.) But the electrons lost from the anode are replaced by oxidizing (removing electrons from) substances in the electrolyte. The oxidized substances migrate in solution to the cathode, where they are reduced (given a supply of electrons), and return to their original state. In the overall process, there is no net chemical change as current flows in the cell.

In an alternative type of photoelectrochemical cell, the solvent or solute can be oxidized and reduced *simultaneously* to generate a fuel. In water solvents containing acid, for example, positively charged hydrogen ions from the acid can be reduced at the photocathode to produce hydrogen, while water can be oxidized at the photoanode to produce oxygen. The choice between generating electricity and producing fuels such as hydrogen depends on whether energy is needed immediately or is to be stored for future use.

While the photoanodes studied so far have delivered impressive results, they have one troublesome drawback: they are very susceptible to photocorrosion. An exposed silicon photoanode, for example, destroys itself within minutes.

A number of investigators have partially overcome this problem by using very high concentrations of electrolyte. For instance, Mark Wrighton of MIT and Adam Heller of Bell Laboratories (Murray Hill, N.J.) report that high concentrations of sulfide ion in solution stabilize cadmium sulfide and cadmium selenide photoanodes so that they can operate for months without appreciable



Hydrogen is added to this doubly bonded molecule (top). The products can consist of two isomers—D and L—mirror images of each other. But unlike many mirror images, the isomers are not superimposable. Such molecules are referred to as chiral. While ordinary catalysts would yield equal mixtures of D and L, chiral catalysts give only one isomer—in this case the L form.

degradation. And West German researchers Heinz Gerischer of the Fritz Haber Institute and Helmut Tributsch of the Hahn-Meitner Institute have discovered that semiconductors made from the disulfides and diselenides of molybdenum and tungsten are inherently resistant to destructive oxidation.

Of the photoanodes studied so far, these molybdenum and tungsten compounds, known as metal dichalcogenides, "seem to be closest to ideal," asserts MIT's Wrighton. In fact, he predicts that such photoanodes may one day play a vital role in pollution control. Wrighton has already tested the materials in the sunlight-driven oxidation of sulfur dioxide—a polluting industrial byproduct—and water to sulfuric acid and hydrogen. This reaction uses 14% of the energy available in light and might be useful for generating valuable hydrogen from the sulfur dioxide emitted by burning fossil fuels.

The materials used in these photoelectrochemical cells are still quite expensive; therefore investigators have been searching for alternatives. One promising approach has been developed by Gabor A. Somorjai of Lawrence Berkeley Laboratory (Berkeley, Cal.). He fabricates electrodes by compressing inexpensive iron oxide powder into small disks, which he then dopes with either silicon dioxide (to make anodes) or magnesium dioxide (to make cathodes). He then cements the disks together to form a diode.

Suspended in sodium hydroxide or sodium sulfate solutions and illuminated, the diodes evolve hydrogen and oxygen. So far, the best efficiency Somorjai has achieved with this system is about 0.1%. A theoretical efficiency of 14% is possible, says Somorjai, and he is "pretty confident that we can reach 1 to 5% in the near future."

Beyond photocatalysts, there are other catalytic areas under intensive investigation. For example, biochemists are developing semisynthetic enzymes that might be able to carry out reactions not possible with conventional enzymes (HIGH TECHNOLOGY, April 1984, p. 51). Molecular biologists are even contemplating the design of entirely synthetic enzymes. Industry officials predict, in fact, that such enzymes, along with other designed catalysts, will make a profound change in the way chemicals and biologicals are manufactured. Says William Amon, Jr., vice-president for business development at Cetus (Berkeley), "We are on the verge of a new industrial revolution." □

Thomas H. Maugh II is on the research-news staff of Science *magazine.*

BUSINESS OUTLOOK

Refinery applications lead catalyst sales

Catalysts are playing an increasingly critical role within the petroleum industry as oil companies try to boost output by squeezing gasoline from even the lowest grades of crude oil.

Refiners consumed more than 2.5 million tons of catalysts last year, and Strategic Analysis (Reading, Pa.) reports that consumption will grow 3% annually over the next four years. The dollar value of sales, however, will increase at 5%, as users turn to stronger, more expensive compounds. Sales were worth $530 million in 1983 and are projected to top $662 million by '88.

Petroleum production accounted for 36% of last year's $1.4 billion catalyst market, chemical applications 32%, and emission control applications the remainder. In the chemical industry, catalysts produce a range of products, including plastics, perfumes, and margarine. Emission control compounds are used for both automotive and smokestack exhausts. By '88, Strategic Analysis expects total sales of catalysts to grow to $1.7 billion, with petroleum applications accounting for 39%, chemical applications 34%, and emission control applications 27%.

Most of the more than 30 catalyst suppliers provide products for only one of the three major market segments. They further focus their efforts by addressing only one or two applications within a given segment. "Each application requires its own set of catalytic compounds," explains Bruce Deckman, a vice-president of Strategic Analysis. "Unless a supplier has the backing of a large diversified parent company, it's difficult for him to be all things to all industries."

But there are exceptions, particularly among companies whose broad product lines are the result of mergers and acquisitions. Gulf Oil and Union Carbide, for example, joined forces in 1982 and merged Harshaw, a Gulf subsidiary specializing in petroleum, and Filtrol, a Union Carbide subsidiary specializing in chemicals. The result, Harshaw-Filtrol (Los Angeles and Cleveland), is now one of the leading catalyst suppliers.

The petroleum industry requires catalysts for five separate processes: catalytic cracking (which produces gasoline), alkylation (which produces high-octane blending components), hydrotreating (which removes sulfur, nitrogen, and metals from oil prior to catalytic cracking), hydrocracking (which produces heating oils), and catalytic reforming (which improves octane levels in no-lead and low-lead gasoline). The market for substances used in catalytic cracking was worth $250 million last year; alkylation, $150 million; hydrotreating, $70 million; hydrocracking, $40 million; and catalytic reforming, $20 million.

Earl

Norris

"In converting residual feedstocks to high-grade fuel, catalysts are helping refiners scrape revenues from the bottom of their barrels."

Gerald Earl
Director, Marketing
Filtrol div.
Harshaw-Filtrol

"The petroleum industry is generating the big revenues in the catalyst business. Most new-product development efforts will be channeled in that direction."

Paul J. Norris
VP, Sales and Marketing
Petroleum Refining Catalysts and Processes
Engelhard

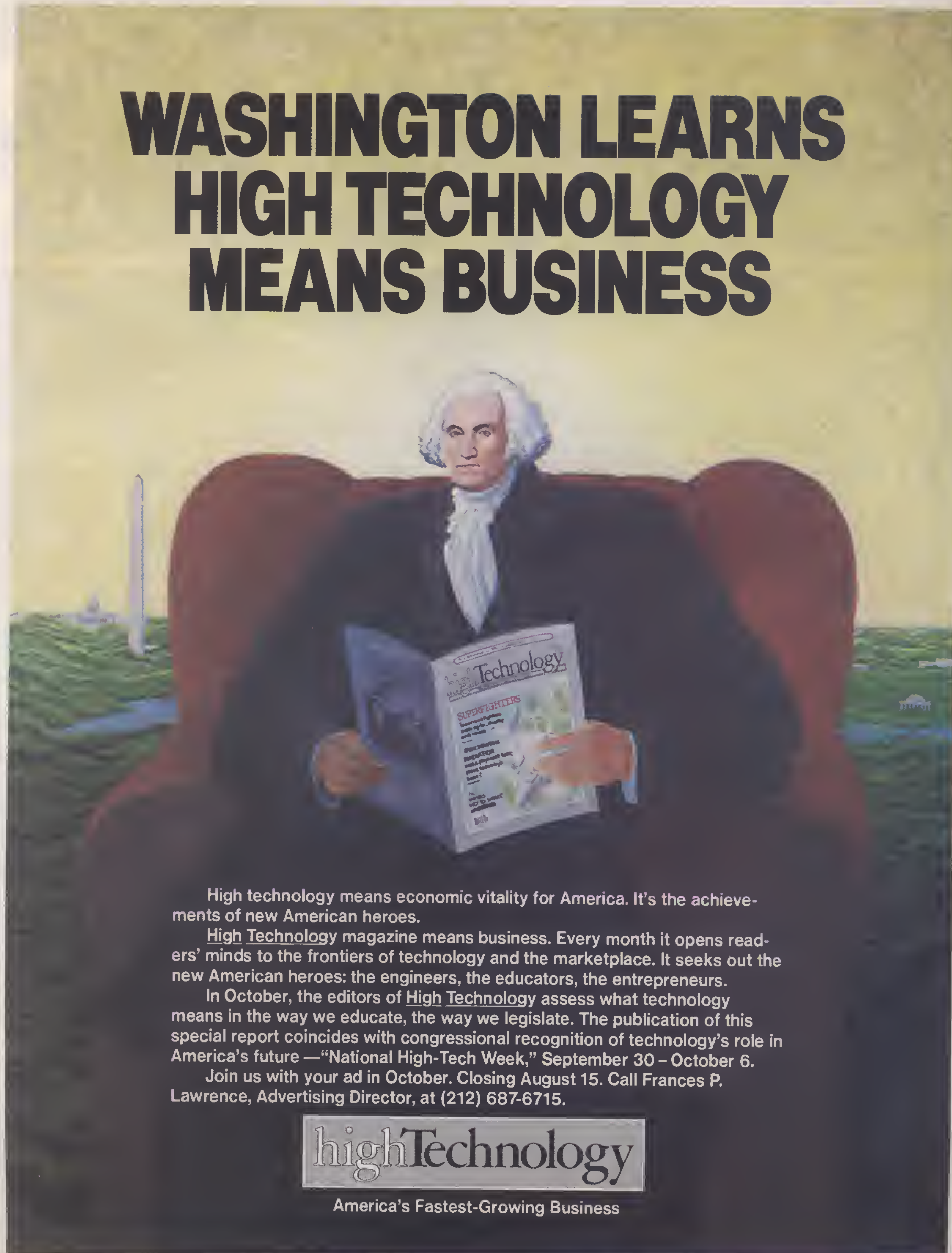
Catalytic cracking and hydrotreating are the fastest growing niches within the petroleum segment. Sales of catalytic cracking compounds are increasing 5% annually, according to Strategic Analysis, and are expected to be worth $315 million in '88. Sales of hydrotreating compounds are increasing 8% annually and should be worth $105 million by '88.

Prices of both types of catalysts range from $600 a ton to more than $2000, according to Gerald Earl, director of marketing for the Filtrol Division of Harshaw-Filtrol. The higher-priced compounds, he says, have longer lifetimes and can remove impurities more selectively.

"Refiners are coming to appreciate the additional earnings they can accrue by processing residual feedstocks," notes Earl. "We have customers who are buying the more expensive catalysts at the rate of 40 tons annually. During the seventies, those same customers bought less than five tons a year of the cheaper compounds." Earl claims that one company has used hydrotreating and catalytic cracking processes to increase the value of its annual gasoline yield by $40 million. "Economics is definitely the driving force in this industry," he says.

Davison (Newark, N.J.), Engelhard (Baltimore), and Harshaw-Filtrol control virtually the entire U.S. catalytic cracking market. Among the leading hydrotreating catalyst suppliers are American Cyanamid (Wayne, N.J.), Katalco (Chicago), and Shell Chemical (Houston).

While both groups have retained control of their respective markets for the past five years, they are facing new competition. Among the recent entries in the business are European catalyst suppliers such as Armak and Katalistics (both of the Netherlands), as well as oil companies such as Mobil, Exxon, and Phillips. "There's a lot of new action in this industry," says Earl. "You can tell business is good."—*F.J.C.*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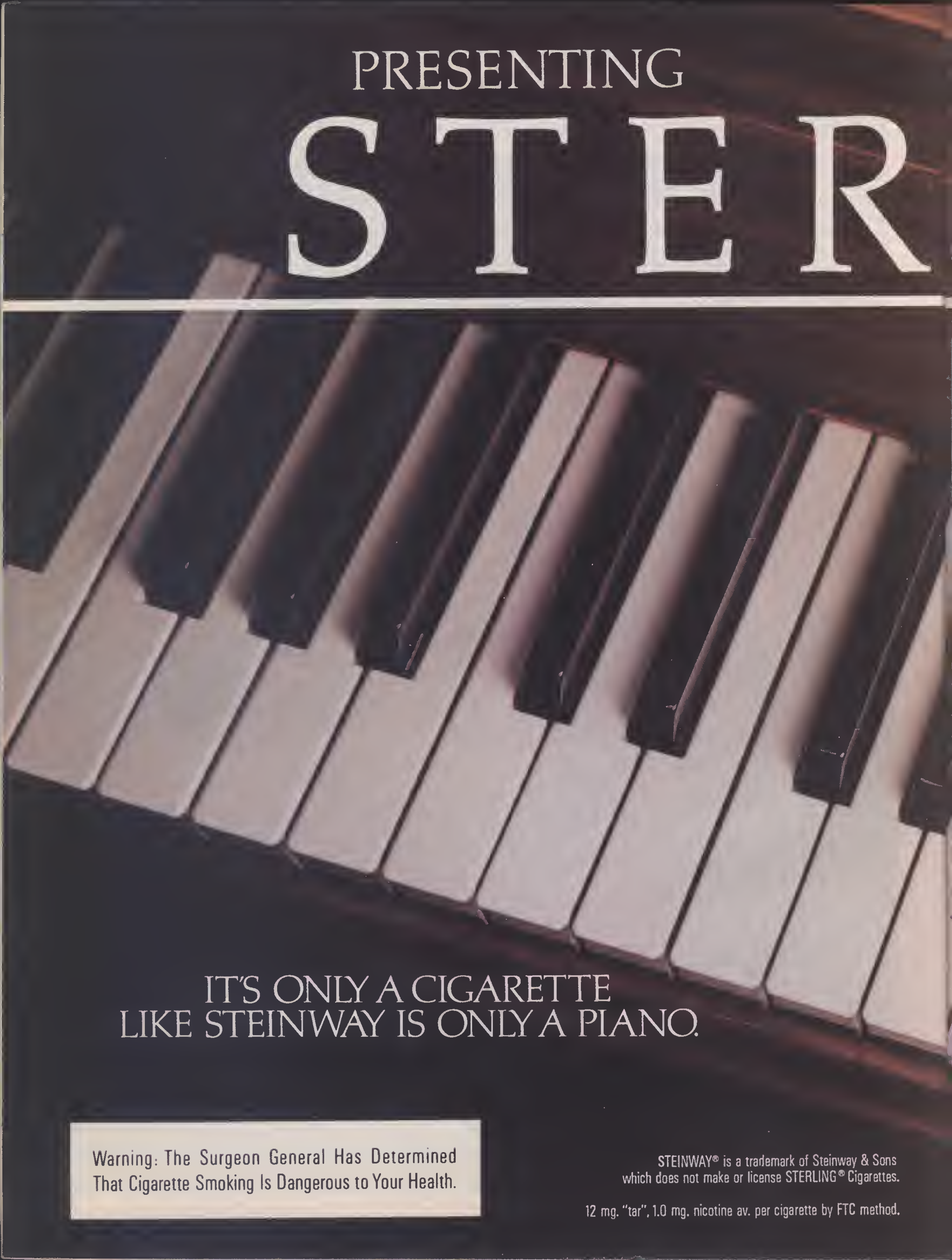
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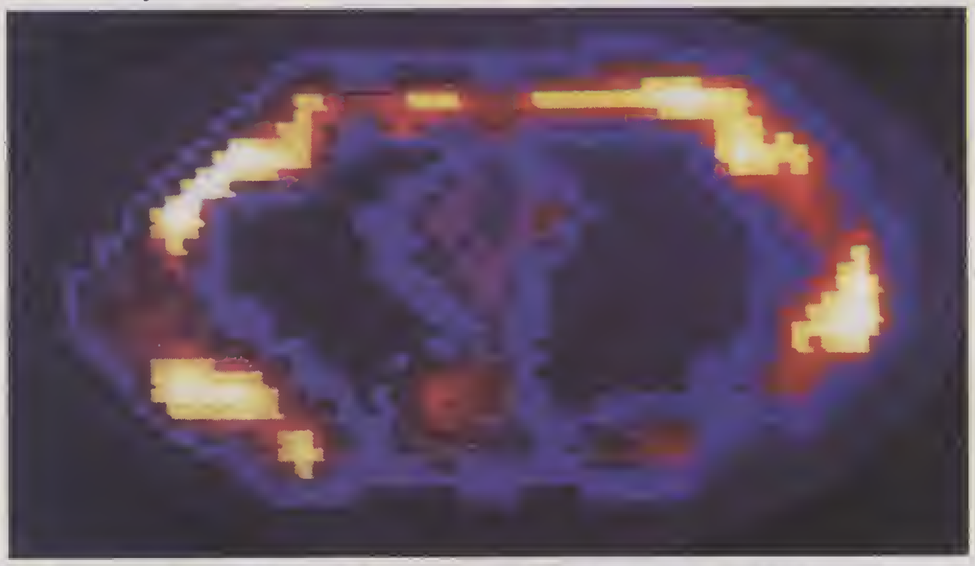
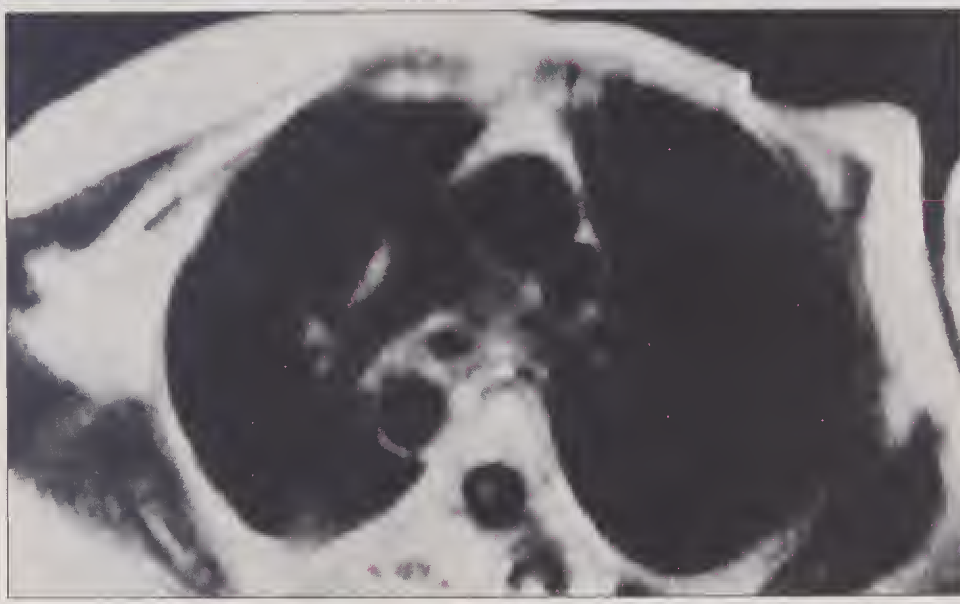
Compare the first NMR image of the human body (top), made in 1977—a "slice" through the upper abdomen—with a modern view of the same anatomic area. Although image quality has improved greatly, researchers still debate NMR's ability to diagnose disease.





(BOTH) FONAR CORP

NMR PROMISES TO KEEP

by Franklin H. Portugal

At the National Institutes of Health (NIH) in Bethesda, Md., a 6-ton superconducting magnet—the heart of a nuclear magnetic resonance (NMR) medical imager—has recently been joined to its power supplies, computers, radio-signal generators and receivers, and display screens. After more than a year of lying about the premises literally in pieces, the imager is finally being used on patients.

At about the same time the NIH device came to life, the Food and Drug Administration, after more than two years of study, approved the routine clinical use of NMR imagers produced by two companies: Technicare (Cleveland)—a subsidiary of Johnson & Johnson—and Diasonics (Milpitas, Calif.). A half-dozen or more other NMR producers, meanwhile, are still gathering experimental data on their imagers to submit to FDA or are now awaiting the agency's approval.

These developments symbolize both the promise of NMR (also called magnetic resonance imaging, or MRI)—a safe, noninvasive means of obtaining new biochemical information about the human body—and the huge amount of data that must still be gathered if the promise is to become reality in more than a handful of facilities. Despite years of study, NMR imaging remains largely in a twilight zone between experimental tool and medical dream machine.

A few of the questions that must be answered before NMR escapes from its regulatory limbo: What type of magnet will deliver the best results at the lowest cost? What are the optimal instrument settings (magnetic field strength, for example) for NMR imaging? For which types of disease will NMR be most helpful? Which elements in the body best lend themselves to NMR imaging, and what information do they carry? And how much can the substantial cost and physical size of today's NMR imagers be reduced?

Pictures of elements. For the purposes of NMR imaging, the human body is an aqueous mixture of elements. Iron is held within red blood cells, bones are loaded with calcium, and the thyroid gland contains large amounts of iodine. Cellular reactions are fueled by a variety of phosphorus compounds, and sulfur plays a vital role in protein construction. Carbon, oxygen, hydrogen, and nitrogen make up the body's myriad organic structures, and trace amounts of about 25 other elements help maintain life processes. By manipulating these materials' nuclei with magnetic fields and radio waves, NMR imaging promises to identify which elements are present, as well as their chemical forms, relative concentrations, and locations (see "The ABCs of NMR").

Simply spotting certain chemicals in the body would provide physicians with important new information about their distribution and transfer. But many of these materials also carry important information about the body's health. Iron deficiency, for example, leads to the range of symptoms that constitute anemia; the condition is now diagnosed by withdrawing a small amount of blood and assaying its iron content. "NMR will one day let us perform such blood chemistries faster and without taking a sample," says Walter L. Robb, vice-president of General Electric and general manager of the company's medical systems operation. Patients will simply place one of their hands inside the harmless bore of the magnet.

For now, however, many important elements remain well outside NMR's reach. And until they are brought within the instruments' capabilities—and until researchers can interpret the information carried by these elements—the technology will be mainly of academic interest.

Iron, for example, is still beyond the sensitivity of today's instrumentation. One reason is that only about 2% of the iron in the body is present as the isotope iron-57, the odd-numbered form detectable by NMR methods. Another reason is that the isotope's gyromagnetic ratio (the ratio of an element's nuclear charge to its spin, a value unique to each element) is very low.

NMR imaging is now based on the detection of the hydrogen nuclei in water. The process is relatively simple because of the body's high water concentration. Moreover, many diseases, including some forms of cancer, appear to alter water distribution within the affected tissues, a change that shows up in computer-reconstructed images.

Many of these images are stunning in their resolution and contrast. But what they reveal about heart disease, cancer, and other disorders is still subject to debate. "Proton density alone doesn't necessarily give you a lot of information," says Richard Knop, an NMR researcher in NIH's department of radiology.

Another question relates to the source of the NMR signal. Some researchers are convinced that it arises from free-moving water in the tissues; others argue that it is generated by relatively stationary molecules. Far from being of mere academic interest, such knowledge will provide insight into the biology of cancer and other diseases, and will thus help physicians determine instrument settings for optimal image contrast.

Yet another issue is optimal field strengths. Researchers must determine the range of instrument settings for a particular disorder, just as a radiologist knows that the x-ray intensity needed to image a broken bone differs from that needed to view the digestive tract. "We're still determining the most appropriate NMR parameters for a given type of patient so we don't miss anything," explains Knop. Until those parameters are known and standardized, patients may be subjected to unnecessarily expensive, time-consuming, and perhaps hazardous studies.

Not surprisingly, physicians have varying expectations from NMR. "We try to match clinical problems with real expectations of what the instrument can do," says Knop. "Some physicians come to us with expectations totally out of whack; others have great problems and don't realize that NMR studies could be helpful."

Beyond proton imaging. While hydrogen nuclei are the basis of today's commercial NMR imagers, the detection and imaging of elements such as sodium and phosphorus form the technology's cutting edge. "The real potential of NMR goes far beyond proton imaging," says GE's Robb. "But this is not something that is going to happen overnight."

One reason for the interest in sodium and phosphorus is that the two elements are sure to provide important details about the body's biochemistry, details unavailable with other imaging methods. "Anatomic changes are almost invariably preceded by chemical changes," explains another GE source.

Is it the new medical dream machine? The questions still outnumber the answers

"The trick is to detect those changes early enough that diagnosis and treatment can proceed."

Both the abundance and the magnetic properties of sodium and phosphorus bring them within the sensitivity range of new instrumentation. Researchers at the Neurological Institute of New York (New York City), working with imagers developed at Holland's Philips Medical Systems, have already imaged both elements in animals and in humans, although the results are still being interpreted.

Sodium imaging may aid in the treatment of strokes. Sodium concentrations increase dramatically at stroke sites, a phenomenon thought to stem from fluid accumulation around the damaged tissues. Although relatively small amounts of fluid are involved, sodium concentration may increase by as much as 600%—a result of fluid accumulation outside the brain cells and the breakdown of a pumping mechanism for transporting the sodium into cells. As the sodium level rises, so does the intensity of the NMR image. Such changes may provide not only a new diagnostic tool but also a means of determining how stroke sites are responding to treatment.

Sodium accumulation at various locations in the heart may yield similar information about a patient's condition after a heart attack. And since sodium is released from the body through the kidneys, sodium-based images might be used to monitor kidney function.

As with proton imaging, however, the relative importance of sodium imaging remains uncertain. "I'm not all that excited about imaging sodium unless I know that it will answer a clinical question that I couldn't have answered otherwise," says Knop.

Phosphorus is of special interest to NMR researchers because it is so important in biochemical reactions. Adenosine triphosphate (ATP), for example, is a rich energy source for the body's cells. And metabolism, the breaking down of nutrients for cell construction or maintenance, is fueled by the breakage of phosphorus's chemical attachments. NMR may one day be able to detect abnormal distributions of phosphorus to aid in diagnosing any of a number of biological malfunctions.

Investigators at the Neurological Institute of New York have obtained images of how phosphorus is distributed in the leg muscles of human volunteers, in essence providing a means of visualizing biochemical reactions. Together with nonimaging NMR methods (called NMR spectroscopy) that have already detected abnormal phosphorus conditions in diseased muscle, phosphorus imaging promises to provide new in-

The ABCs of NMR

Nuclear magnetic resonance (NMR) imaging is based on the magnetic properties of nuclei containing an odd number of protons. Virtually every such nucleus has a natural spin, making it in effect a tiny magnet.

It is well-known that the end of a magnet is either attracted to or repelled by another magnet. When the nuclei are placed in a magnetic field, therefore, their natural spin directions are altered. Many of the nuclei line up with the field and in so doing assume a new energy state. The nuclei also rotate (precess) around their axes at characteristic frequencies, much like wobbling spinning tops.

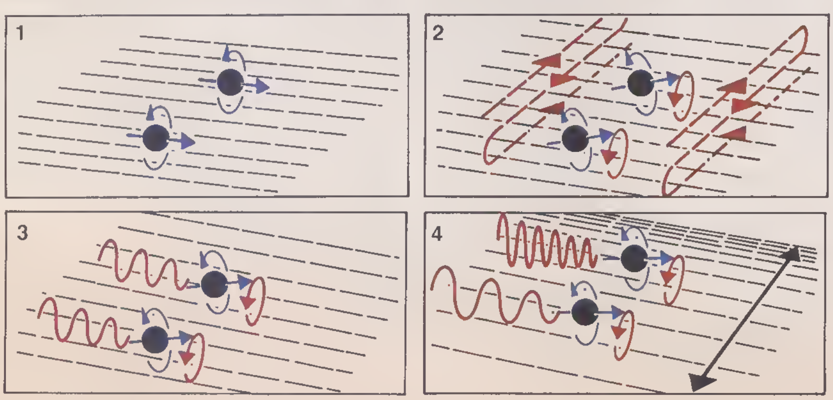
The rotational angle can be altered by introducing another magnetic field at a radio frequency to match that of the nuclear precession. This phenomenon is known as resonance; it is similar to causing a tuning fork to vibrate by singing a note at the same pitch. When the radio signal is switched off, the magnetized nuclei induce a signal in adjacent receiver coils. As the nuclei return to their initial precession state, this signal decays at a rate characteristic of the particular nucleus. The spin-lattice relaxation time (T_1) is the time needed to convert spin energy into thermal energy and to transfer it to the molecular lattice of other atoms. The spin-spin relaxation time (T_2) is the time needed to transfer spin from nuclei in a high energy state to neighboring nuclei.

The signals' exact frequency, phase, and strength are then assessed through a mathematical process known as a Fourier transform. The signals are assigned specific shading intensities—black representing a very strong signal, for example, and white representing no signal—enabling a computer to translate the results into a density "map" of atoms such as hydrogen, the body's most abundant element and thus the easiest to image with today's instruments.

When hydrogen nuclei (protons) in the body are imaged with NMR, dense substances like bone, which normally block x-rays, become transparent. The reason is that bone contains little water, the major source of these protons. Soft tissues like the gray and white matter of the brain, however, are imaged in great detail because they contain much water (albeit different amounts in different types of brain tissue). NMR can thus image portions of the brain previously hidden from CT scanners by the skull.

Over the past 20 years, NMR sensitivity has increased almost 400 times, thanks to advances in magnetic field generation, in spectroscopy (the study of chemical compounds through their electromagnetic energy absorption characteristics), and in instrumentation. Although NMR is not yet capable of imaging certain scarce elements (iron-57, for example), its great potential has kept the R&D fires burning, and improvements continue to bring other elements closer to NMR visualization.

Protons (hydrogen nuclei) normally spin randomly about their axes, but are aligned by a strong magnetic field (1). A second, alternating field at right angles to the first makes the protons wobble about their axes, or precess (2). When the second field is shut off, the protons attempt to return to their previous state, generating radio signals that are detected in nearby receiver coils (3). These signals have a decay rate, or "relaxation time," unique to each particular type of nucleus. Images are formed by graduating the strength of the first field (4) and by mathematically analyzing the signals to determine their location in the body.

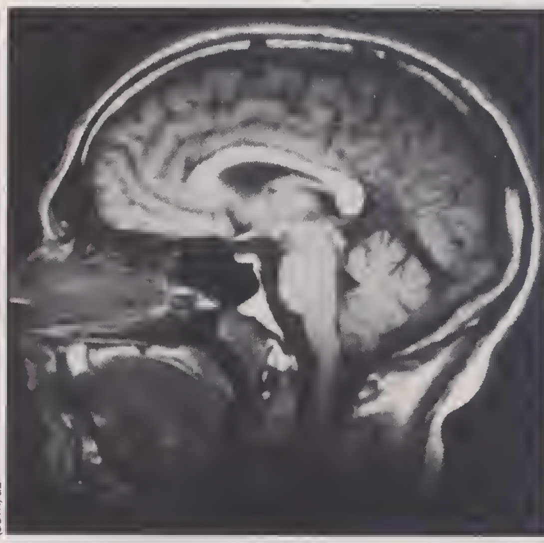


MARK E. ALSOP

sights into how human tissue functions.

Phosphorus imaging may also be useful in cancer studies. Physicians now have no way of quickly determining the growth rates of certain brain tumors, for example, but it is reasonable to expect that fast-growing tumors would have large ATP reserves. Besides aiding diagnosis, such imaging could be made during therapy so that physicians could tell whether the treatment was slowing the growth of the tumor, simply by comparing phosphorus concentrations over a period of time. Likewise, phosphorus imaging may aid cardiologists in spotting weakened heart muscle tissue, urologists in predicting the success of kidney transplants, and pediatricians in determining if high-risk newborns are suffering irreversible brain damage due to oxygen deficiencies.

A patient is prepared for an NMR scan. Powerful superconducting magnets such as this one require extensive and costly shielding to prevent interference with electronic equipment and metallic objects up to 60 feet away.



(BOTH) GE

The brain's soft tissues are clearly visible in this head image, made at a magnetic field strength of 1.5 tesla. With NMR proton imaging, unlike certain other techniques, the low water content of bony structures such as the skull renders them transparent.

Fluorine studies. Yet another element of special interest is fluorine. But while sodium and phosphorus imaging are moving from the laboratory into the hospital, fluorine imaging remains in the research stage.

One reason is that for many years there was little interest in such imaging, because fluorine occurs in the human body only in relatively small amounts. But now this scarcity is being turned to good advantage: It means that under certain conditions, fluorine introduced into the body will produce strong signals unobscured by background "noise."

Many important surgical anesthetics contain fluorine. But how these agents affect the human nervous system and induce deep sleep remains a puzzle. Little is known of where in the brain the anesthetic goes or even how long it stays there.

This ignorance is unlikely to last much longer. Even without imaging methods, NMR has already produced some surprising findings. Using lab animals and NMR spectroscopy, Alice Wyrwicz, assistant professor of chemistry at the University of Illinois (Chicago), has found that fluorine anesthetics remain in the brain five times longer than previously thought. Such studies cast light on how anesthetics are absorbed and distributed, how they work, and how long they take to produce anesthesia.

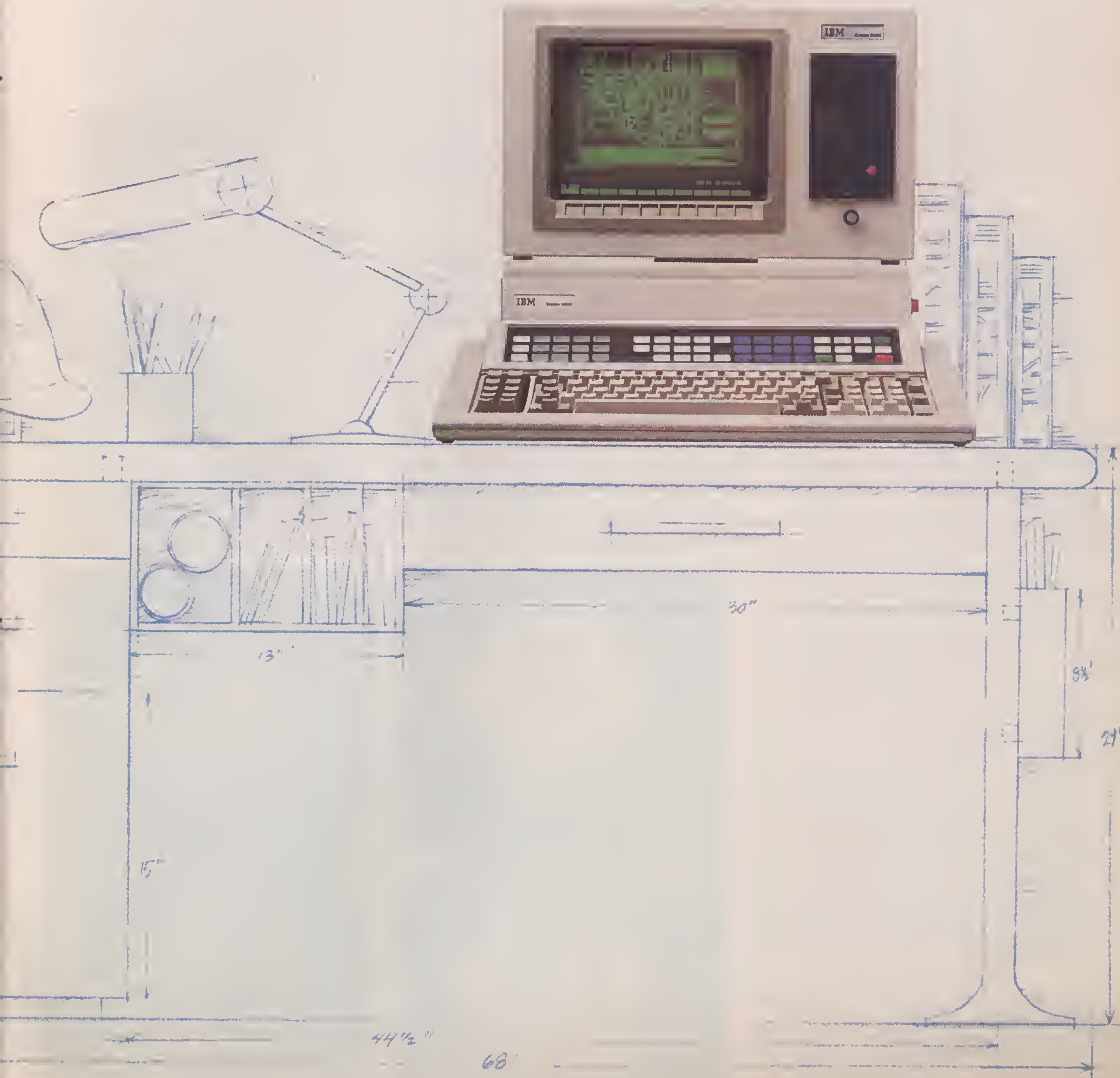
Now Wyrwicz's group is moving on to imaging methods to help answer these questions. Wyrwicz thinks the necessary technology is already available, although experimental parameters are still being developed. A potential problem with such studies, for example, is that because fluorine is naturally scarce in the body, compounds containing it above a certain concentration may be toxic. At the same time, the imaging of such scarce chemicals now requires very high magnetic fields or long scan times, both of which are costly and perhaps hazardous.

Fluorine imaging could be helpful in other areas. Certain fluorine-containing chemicals, such as 5-fluorouracil, appear to be useful in treating and destroying tumors. NMR could thus help visualize sites where the drug is or is not at work. Yet another potential application—blood flow studies in deep, relatively inaccessible organs, such as the liver—might also be realized with recently developed blood substitutes. These compounds, based on biologically inert fluorinated hydrocarbons, are easily distinguished from surrounding tissues. Therefore they may one day be used to determine flow rates within smaller vessels deep inside the body.

Blood flow calculations (as an indicator of the heart's pumping efficiency, for example) are already performed with ultrasound, an imaging method based on high-frequency sound waves. But NMR may offer several advantages over ultrasound. First, NMR is not limited to blood vessels close to the body's surface. Nor is NMR's accuracy affected by impeded or obstructed blood flow. (Modern ultrasound devices use Doppler principles to calculate flow rates by recording and imaging echoes from a moving body, and so may be distorted by erratic flow.) Moreover, NMR provides a detailed anatomical image of the vessel in addition to blood flow data.

Blood velocity can be determined by NMR even without fluorine. Researchers from the University of California's department of electrical engineering and computer sciences (Berkeley), working with radiologists at UC San Francisco, have used proton imaging to calculate blood flow in a specific volume of a vein. Using NMR pulse sequences, "snapshots" are taken at close intervals (usually 50–500 milliseconds apart) of the volume of polarized blood—that is, blood in which a net magnetic moment, or orientation, has been induced—flowing into a region of the vein. From the image itself, the average cross-sectional area can be obtained and the flow velocity calculated. Blood flow rates are com-

the talented tackle technical.



Which type of magnet is best?

As a diagnostic tool, NMR imaging may be the answer to physicians' prayers. But In the case of imagers based on high-powered superconducting magnets, the machine itself must be approached with care. Otherwise it may throw the hearts of pacemaker wearers into a frenzy, erase recording tapes and the magnetic strips on credit cards, and bring mechanical watches to a halt.

These effects are due to the core of the instrument—a doughnut-shaped magnet that stands more than six feet tall and weighs about six tons. Today's superconducting magnets generate field strengths of up to 14 tesla, or about 300,000 times greater than the earth's magnetic field. (One tesla, or T, equals 10,000 gauss.)

Most researchers agree that NMR image resolution is generally proportional to the field strength. Moveover, the higher the field, the greater the number of elements that can be located and imaged. There is considerably less agreement on how strong a field is really needed: Since even whole body imaging can be done with the fields generated by permanent magnets (approximately 0.3 T), some researchers question whether the large and costly superconductors are needed at all.

"There's a trade-off between field strength, cost, and image quality," says H. H. Tuithof at Philips Medical Systems in Holland. "Some companies shoot images of dead bodies for 30 minutes at a low field strength. They get great pictures, but that isn't very practical for a major institution that's concerned about fast patient turnaround time." Nor would most patients be capable of lying motionless in the unit's close confines for such extended periods.

Three types of magnets are now under investigation for NMR imaging: permanent, resistive, and superconducting. Each has its share of devotees and detractors.

The biggest advantage of permanent magnets is that they do not require electrical power. Nor is expensive shielding necessary, because of the minimal fringe field (the area surrounding the magnet within which metallic objects are affected). This type of magnet, however, generates very small fields relative to its size. In fact, one of the largest permanent NMR magnets available today weighs

puted from these data, providing a measure of heart function and helping to assess drug effects.

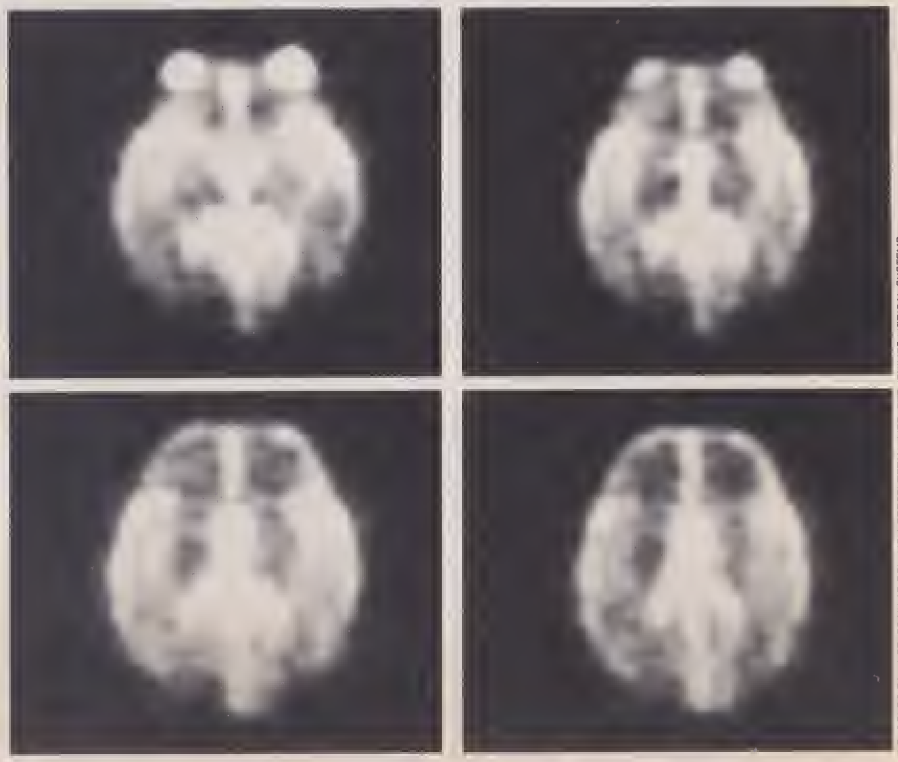
NMR technology is being perfected for imaging other types of internal body movement as well. For example, real-time movie images of a rabbit's beating heart have been made recently in England by Peter Mansfield and his colleagues at the University of Nottingham; the scans consist of 6 images obtained over a 32-microsecond period. Within the next few years, NMR imaging of a beating human heart will also be routine. Combined with images based on phosphorus, sodium, and other important metabolites, the result will be important new information on the heart. "Cardiac imaging is a whole new area for NMR," says H. H. Tuithof, a researcher at Philips Medical Systems (Eindhoven, Netherlands). "We expect to derive much new information on the heart's structure, tissue characteristics, and output."

Technical improvements will hinge largely on a process called gating, in which the imager is connected to an electrocardiograph or other signal detector. An image is made by reconstructing the data obtained from a series of snapshots, each taken at a precise point in the heartbeat. The method will mean longer effective imaging times and the minimization or elimination of blurriness.

Carbon, as the isotope carbon-13, is yet another element within reach of today's NMR technology. Like fluorine-19, it is present in the body only in small amounts; hence it can be used to label drugs for tracking.

Problems still abound. For all NMR's promise, there are still many unproven claims about its diagnostic value. It is also far from being the perfect imaging system. Pacemaker wearers are excluded because of interference by the powerful magnetic field. Patients whose bodies contain surgical clips are also ruled out, because the field may produce torque and other hazardous movement of the clips. (In the future, of course, the problem can be avoided with nonmagnetic clips.)

Another disadvantage of NMR is its high cost—not simply the cost of the magnet (which can run into hundreds of thousands of dollars in the case of modern superconducting units, or up to 30% of the system's total cost), but also that of the liquid helium and liquid nitrogen needed to maintain the superconducting magnet's low temperatures. Moreover, rooms housing NMR imagers require thick, expensive shielding because the machine's stray magnetic



NEUROLOGICAL INST. OF NY AT COLUMBIA PRESBYTERIAN MED. CTR./PHILIPS MEDICAL SYSTEMS

In these sodium-23 images of the head, the eyes are visible in the top photos. The brain's ventricles, or cavities, appear as large white spaces. Such NMR images may deliver more information about the body than those made from hydrogen protons, because of sodium's unique distribution in many biochemical processes.

100 tons but generates only a 0.3-T field.

Resistive magnets, which generate a field via the flow of electrical current, contain either iron or air cores and produce fields to about 2.4 T. They consume considerable quantities of power and require large water-cooled systems. "It's like having a great big iron plugged in all the time," explains one researcher.

Superconducting units are special types of resistive magnets. The superconduction is due to the use of materials that lose their electrical resistance at very low temperatures: Near absolute zero (−273.15° C), current continues to circulate through a superconducting system even while the power source is off. As a result, the system generates a continuous field without drawing additional power.

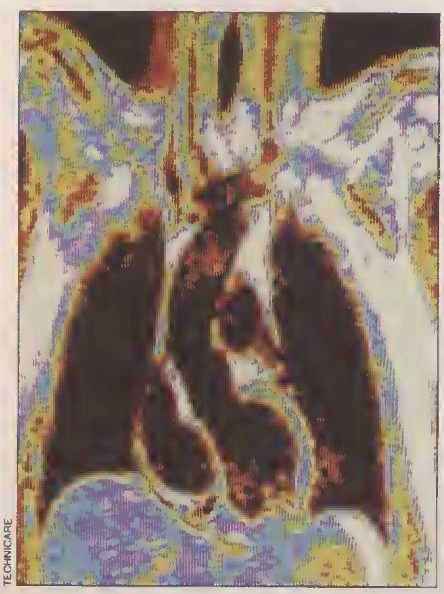
Typically, such a magnet consists of a superconducting wire core enclosed in two vacuum flasks. The wire is usually made of niobium (which becomes superconductive at the highest possible temperature) combined with tin or titanium. Liquid helium in the inner vacuum flask cools the conductor to near absolute zero. The outer flask uses liquid nitrogen to keep the more expensive liquid helium cold.

Superconducting magnets are limited by their high manufacturing and maintenance costs. Some 36 miles of conductor may be used in a typical 1.5 T magnet, at a cost of about $200,000. Users must also have cryogenic apparatus for replenishing the liquid helium and liquid nitrogen. With a typical superconducting magnet boiling off about a quarter liter of liquid helium per hour (at up to $8 a liter), the cost could be considerable.

Another disadvantage is that superconducting magnets have a relatively large fringe field, extending up to 60 feet or more from the magnet. That requires elaborate shielding—typically adding hundreds of thousands of dollars to the siting cost—to prevent interference with nearby equipment, vehicles, furniture, and even the structural members of the building. The far-reaching field can also create unusual hazards to workers and patients: Otherwise innocuous objects like hairpins, keys, and mechanical pencils fly toward the magnet as though shot from a rifle—with the same deadly effect on whoever happens to be in the way.

forces can affect objects up to 60 feet away. The field may also disrupt the functioning of nearby x-ray machines, CT scanners, and video equipment.

There also remains the question of NMR's safety. Extensive tests on animals and humans have produced no evidence of physiological hazard. But because the technology is so new, and because harmful effects may take years to manifest themselves, cautious U.S. regulatory agencies have limited the magnetic field strength to less than 2 tesla. As an additional safeguard, children and pregnant women are subjected to NMR imaging only when it may provide vital information not otherwise available.



NMR may prove an important cardiac study tool via gating—eliminating blurred images of the beating heart by linking the scan to an electrocardiogram. The lungs, aorta, and main chambers of the heart are clearly visible in this gated image.

Yet the hazards may turn out to be minor—especially when compared with those of frequent exposure to x-rays, as with CT scans. (CT scanners have encountered a host of problems—most relating to unreasonably high exposure to ionizing radiation—resulting in at least 13 recalls since 1977.)

As to whether NMR may soon replace CT, as some have suggested, the outlook is mixed. "Radiologists find the quality of NMR images outstanding, especially brain images, which have been promoted most often," says Edwin Becker, associate director for research services at NIH. "In many cases, they're probably better than CT scans."

Image quality aside, however, there are areas in which NMR and CT are less apt to compete with each other. While NMR provides valuable information about the tissues' chemical function, CT gives only structural data. "CT cannot differentiate between the white and gray matter in the brain, for example," says Philips's Tuithof. "It also misses certain tumors that are differentiated quite readily by magnetic resonance." But although NMR yields high-resolution images of the body's soft tissues, it cannot now image bone, because of the latter's low water concentration. Orthopedic patients will continue to require imaging systems such as CT scanners, at least until calcium and other major bone elements can be detected. Therefore it seems likely that the two types of imagers will be complementary tools (for institutions able to afford the luxury of both, at any rate) rather than marketplace competitors.

NMR imagers may also have an impact on ultrasound devices, at least in some settings. Working with aborted fetuses, NMR researchers have already attained a level of anatomical detail that equals or surpasses ultrasound. Here again, however, cost and size will probably be the deciding factors at most locations. While an ultrasonic device can easily fit into a doctor's office and may cost mere thousands of dollars, a 1.5-tesla NMR machine needs at least 300 square feet of space, plus shielding and auxiliary equipment, at a total cost of more than a million dollars. As a result, ultrasound's niche in obstetrics and gynecology seems secure for many years. Once NMR's safety is established, however, it could be used to verify or rule out conditions that fall outside ultrasound's capabilities.

On balance, the potential uses of NMR imagers are undeniable, says GE's Robb: "There's no question that NMR diagnostics are going to keep improving over the next 20 years. Today the technology is at about the same stage of development as x-rays at the turn of the century. Twenty years from now we will routinely be imaging the body's interior and performing chemical analyses and blood flow measurements, able to see the difference in composition between arterial and venous blood while it is flowing through the patient. In short, NMR's impact on diagnostic medicine a few years down the road is far beyond anyone's dreams today." □

Franklin H. Portugal, a former senior staff fellow with the National Institutes of Health, writes frequently for technical and popular magazines.

For further information see **BUSINESS OUTLOOK** *on next page and* **RESOURCES** *on page 78.*

BUSINESS OUTLOOK

Magnetic resonance firms face slowdown

Just when the stage was being set for the nuclear magnetic resonance (NMR) system market to take off, medical equipment suppliers have begun to experience a downturn in sales. The downturn is the result of new federal regulations that limit the amounts hospitals can charge Medicare for 467 categories of patient care. To compensate for any decrease in earnings the regulations might cause, the health care industry is temporarily cutting back on capital equipment purchases.

Until spending resumes, NMR suppliers are being forced to sacrifice short-term profits for long-term rewards. Rather than trying to sell their systems to price-conscious buyers, they are placing them either gratis or for a nominal fee. This strategy has been used with as many as 75% of the more than 200 NMR systems that have been installed so far and is expected to eventually help spur the market on at a 50% annual growth rate within the next six years.

"The real promise of NMR may indeed lie in in-vivo spectroscopy. But it may take another ten years of research before that application is of clinical merit."

James L. Carolan, President
Nalorac Cryogenics Corp.

NMR sales will increase from $90 million this year to more than $1 billion by 1990, predicts Wayne Fritzsche, an analyst with the market research and consulting firm Fritzsche Pambianchi & Associates (Somerville, N.J.). While the NMR market now accounts for only 1.2% of the total $5.4 billion medical imaging market, it should represent more than 15% by the end of the decade.

"Considering the current climate, it's unlikely that hospitals are going to shell out as much as $1.2 million for an NMR system," notes Fritzsche. "The only way suppliers will be able to generate widespread interest in the devices is to do basic missionary work. They have to get their units installed—at any cost—in as many prestigious institutions as they can. That way they'll reach the real movers and shakers in the industry who will influence buyers down the road."


Carolan


Glenn

By virtually giving their systems away, suppliers are getting more than exposure in return; they are also acquiring clinical data to help them better understand the range of capabilities that NMR provides.

Although NMR's ability to provide images of soft body tissues is well documented, its spectroscopy applications are still uncertain. While imaging gives diagnosticians a cross-sectional view of a heart muscle, for example, spectroscopy provides more detailed information about the biochemistry of specific cells. "The more specific the information a physician has to work with, the more accurate a diagnosis he is able to make," notes Arthur Glenn, general manager of the magnetic resonance department within GE's Medical Systems Group (Milwaukee).

Once NMR's spectroscopy capabilities are better understood, the application could help drive the market. Now, however, it is confusing potential buyers who are hesitant to invest in a system that may be incapable of cellular analysis. "No one wants to be locked into a machine that only does half the job," says Fritzche. While imaging can be handled by NMR units with field strengths as low as 0.3 tesla, researchers say that spectroscopy may demand more powerful machines, with field strengths ranging from 1.5 to 3 tesla.

More than 20 companies are scrambling for positions in the NMR market, but a shakeout is going to eliminate most of them, contends George Stasen, president of the investment consulting firm Medical Technology Fund (Flourtown, Pa.). Among the larger market participants are GE, Johnson & Johnson's Technicare division (New Brunswick, N.J.), West Germany's Siemens, the Netherlands' Philips, and Japan's Hitachi. Smaller vendors include Diasonics (Milpitas, Cal.), Brooker Instruments (Billerica, Mass.), Fonar (Melville, N.Y.), Nalorac (Concord, Cal.), and Israel's Elscint.

Technicare and Diasonics currently have an edge in the market because they were the first to win Food and Drug Administration approval to sell their units for use on the general public. Fritzsche claims, however, that the eventual leaders will be the established medical equipment suppliers with the financial backing to weather losses until the market picks up. He predicts that GE will command the largest share, followed by Philips and Technicare.

"While NMR systems require a hefty initial investment, they could help lower medical costs over the long term by speeding diagnosis, eliminating many expensive and dangerous exploratory surgery procedures, and reducing hospital stays."

Arthur Glenn, General Manager
Magnetic Resonance Dept.
Medical Systems Group, GE

"The only way for the smaller companies to survive will be to pick a niche that the larger players aren't interested in," Fritzsche says. Nalorac, for example, plans to target its NMR systems for research applications and does not intend to go after the clinical diagnostic market.

"The big guys want to channel all their research and marketing strengths into the larger clinical market and don't want to divert their attention to smaller, less expensive machines," says Nalorac president Jim Carolan. "But there's a sizable demand out there for research systems, and we feel we can make our greatest impact addressing that demand."—*F.J.C.*

PERSPECTIVES

International joint ventures

Unlike the steel, auto, and other mature industries, in which tariffs dot the geopolitical landscape like smokestacks, most high technology industries are relatively free of trade barriers. "But for a company with a product that it thinks might be useful to the overseas market, there are other barriers to local entry that may be just as imposing," notes Kenneth Bosomworth, president of International Resource Development (IRD), a consulting firm in Norwalk, Conn. Such obstacles include unfamiliar language, culture, and business practices.

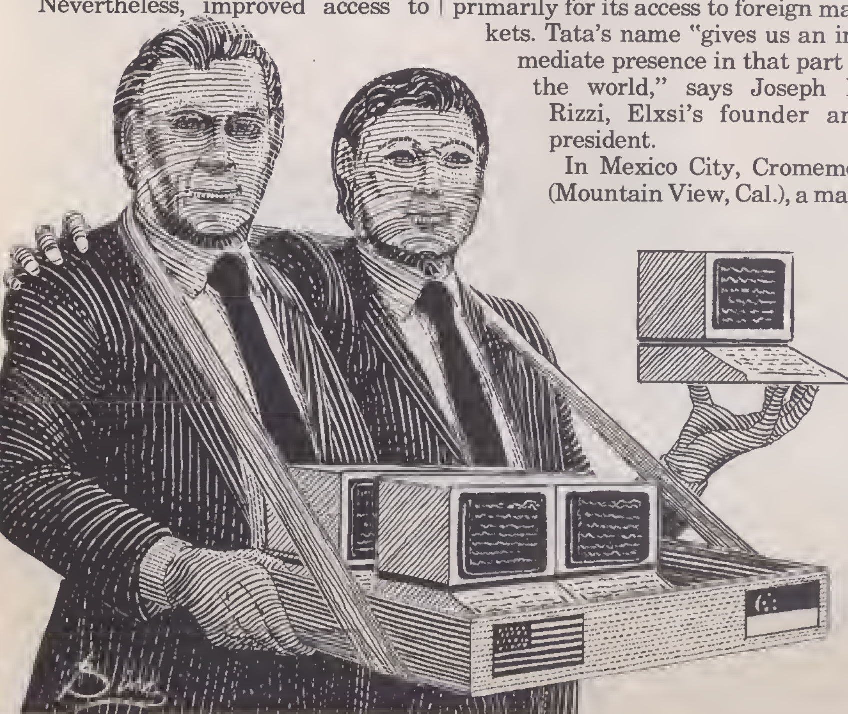
So in order for U.S. companies to take advantage of the growing foreign market, international joint ventures are cropping up everywhere. By merging their sometimes divergent skills and resources, companies can quickly establish themselves in new markets and gain access to technology that might not otherwise be available.

Joint ventures, however, may face unusually complex problems. Maintaining them requires a daunting amount of work. With representatives of both companies on the board of directors, forging a consensus can be difficult—especially when businesses from different cultures may have divergent expectations for the venture.

Nevertheless, improved access to technology is a powerful incentive to joint ventures. "When you first start out, you look for a company with complementary technology," says John Whyte, a pioneer in international joint ventures and chairman of Astronet, a new Florida-based joint venture in cellular radio (mobile telephone systems) with Mitsubishi. "Usually the project starts out as an idea with one or two people in your strategic planning department. Then you look around to see who's available, who isn't, who's already preempted from dealing with you because of an arrangement with a competitor, and so forth."

In many cases joint ventures are not just advisable for getting into foreign markets—they're mandatory. Countries such as India require joint ventures in order to promote technology transfer from foreign to domestic industry. But the flow of information does not always go from developed to developing countries. For example, Elxsi (San Jose, Cal.), a manufacturer of general-purpose computers, is taking advantage of foreign technology via a joint venture. Elxsi joined with Tata, a $2.5 billion Indian conglomerate, and the Singapore government in an $8 million start-up manufacturing and marketing firm in Singapore. Tata has contributed its expertise in software engineering to the partnership.

But Elxsi chose Tata, which owns slightly under 50% of the new firm, primarily for its access to foreign markets. Tata's name "gives us an immediate presence in that part of the world," says Joseph D. Rizzi, Elxsi's founder and president.



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In Mexico City, Cromemco (Mountain View, Cal.), a manufacturer of multiuser computer systems, recently set up a small joint-venture assembly operation, of which 51% is owned by Mexican interests. "You're not allowed to ship products into Mexico without such a partnership. Apple Computer recently formed one down there too for similar reasons," reports Harry Garland, Cromemco's founder and president. The U.S., for its part, imposes few restrictions on joint ventures—other than Commerce Department controls on export of technology to the Soviet bloc.

Once established outside the U.S., American companies can tap new financial resources. Elxsi's decision to open the plant in Singapore, Rizzi says, allowed the company to draw on local Asian investors for needed capital—"resources that we previously didn't even know were there."

Alternatively, a U.S. firm may seek out foreign companies because they can offer services unavailable in the U.S. In 1982, for example, General Motors and Fujitsu Fanuc formed GM-Fanuc (Troy, Mich.), primarily to provide industrial robots for GM's far-flung auto empire. There may have been "some concern" at first about teaming up with a Japanese partner, says GM-Fanuc president Eric Mittelstadt, but in 1981 GM had no choice. The automaker would need 14,000 robots by the end of the '80s. "At the time, we did not see a robot vendor that could provide those kinds of numbers," he says. So GM, which had already developed several robots in-house, approached Fanuc. Started with $10 million in seed capital, GM-Fanuc could post $70 million in sales by year's end, making it the leader in the emerging U.S. robot marketplace, according to market researchers at Prudential-Bache (New York). GM-Fanuc has already outstripped its parents' expectations. "By the end of 1985," Mittelstadt predicts, "no more than half our sales will be automotive-related." The joint venture, he says, has "more than doubled Fanuc's robot output since the formation of the company."

Some U.S. companies, however, are voicing concerns about potential antitrust violations. In addition to GM-Fanuc, GM also recently set up New United Motor Mfg. (Fremont, Cal.), a 50-50 joint venture with Toyota to build subcompacts. Chrysler promptly challenged the formation of the new company before the Federal Trade Commission. "Our objection from day

one is that this joint venture is a merger between the number one and the number three automakers in the world," a Chrysler spokesman says. "That's not good for the economy, and that's not good for the industry." Although the FTC subsequently ruled in GM's favor, a federal district court judge in Washington, D.C., has since decided that Chrysler is entitled to appeal the FTC ruling. "We hope to have this issue resolved by the end of the year," a Chrysler official said.

Although many joint ventures pose no threat of antitrust violations, there are other potential problems. Both companies must agree on the ground rules of the partnership and on their future plans. In many cases the firms ought to sign a "prenuptial agreement," suggests Anthony Marolda, a management consultant on joint ventures for Arthur D. Little (Cambridge, Mass.). "Typically, these joint ventures are 50-50 deals with a board of directors that's split down the middle," Marolda says. "When the board disagrees, that's when you run into trouble." So it's important to have a bail-out plan ahead of time.

After the planning comes a lot of hard work—perhaps more work than either partner anticipates. "If you can do it with a wholly owned subsidiary, do it," advises Earl Wantland, president of Tektronix (Portland, Ore.), a manufacturer of instrumentation equipment. "Joint ventures generally take a heck of a lot of management energy, compared to an equivalent-sized wholly owned operation."

Wantland's experience comes from Tektronix's pioneering joint venture—begun in 1964 with SONY/Tek—a Tokyo-based partnership to manufacture and market test-and-measurement equipment in Japan. At the time, Wantland recalls, Tektronix was "being squeezed out of the market" by government controls on foreign currency; paperwork and delays were paralyzing the company's sales efforts. "The only real alternative," he says, "was a joint venture." Tektronix teamed up with Sony, and today, Wantland reports, SONY/Tek has sales "in the neighborhood of $100 million."

But the partnership "gobbles up more time and energy and resources than most people would imagine," Wantland says. "I travel to Japan twice a year for board meetings, and I have two executive vice-presidents and one vice-president who also have to shuffle back and forth." Unlike wholly owned operations, it is difficult to delegate responsibility for strategic direction to middle-level management.

Many partnerships look good on paper, warns IRD's Bosomworth, but after a few years of wrangling, they'll die on the vine. They are only successful, adds A. D. Little's Marolda, if both companies know what they're getting into. A Japanese company, for example, is typically willing to accept much lower profits during its start-up phase than its American counterpart, he points out. And if the two parties don't forge initial agreements about such concerns as return on investment, the partnership can quickly split.

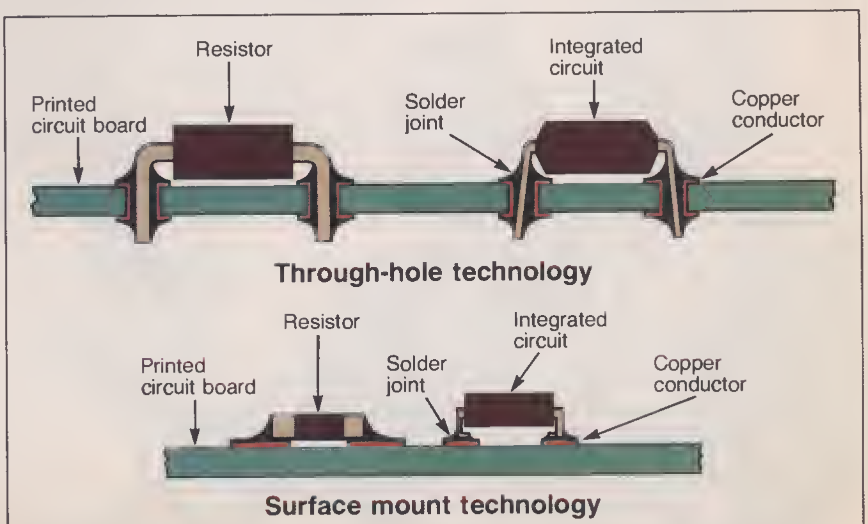
"A joint venture is a little like a marriage," Mittelstadt says. "It works out best when both partners think they're getting the better part of the deal." □ —*Al Furst*

Surface mounting shrinks electronic packaging

Many believe that surface mount technology is one of the most significant developments in electronic packaging since the invention of the printed circuit board; every segment of the industry, from consumer electronics through computers to the highest-reliability military equipment, is being reshaped by its introduction. Surface mounting allows an integrated circuit (IC) package to be shrunk by a factor of three or more. Manufacturing cost, reliability, and electrical performance are also vastly improved.

A printed circuit (pc) board is essentially a means of simultaneously connecting all the components of a fiberglass or paper-based support on which layers of conductive copper have been etched. Conventionally, the wire leads of individual components are inserted through holes in the board and soldered to copper traces. But in surface mounting, components are soldered directly to the board.

However simple this change might appear, its effects are far-reaching. For example, in traditional printed-circuit fabrication, the wire leads have to be fairly large to survive insertion. Moreover, a practical minimum distance between adjacent leads is 0.1 inch; it is this spacing requirement that determines the size of the IC package. When the industry-standard dual-in-line package (DIP) was developed, ICs were relatively simple and required few leads. As ICs became more complex, the number of leads multiplied. Only a few years ago, there was little need for packages with more than 16



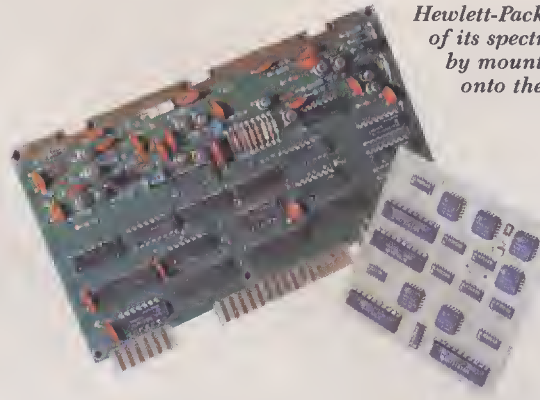
Surface mount technology does away with the wire leads from individual electronic components and hence the need to drill holes in the printed circuit board. The result is a much smaller package that is also less expensive to manufacture. Surface mounting is accomplished as follows: Solder paste is silkscreened onto the bare pc board, and the paste holds the components firmly in place until soldering is complete.

MICHAEL ORZECH

leads, yet packages with 100 or more leads are now common. The DIP has thus become painfully inefficient. A circuit occupying only ¼ square inch of silicon might require a package 15 times larger simply to accommodate the leads.

Hence surface mount technology is being embraced by electronics manufacturers. The technology seems poised to sweep through the industry. "In five years, over 90% of all electronic manufacturers will be using some form of surface mounting," predicts Don Brown, president of the consulting firm D. Brown Associates (Warrington, Pa.). According to North American Philips's SMD Technology Center (Milwaukee, Wis.), surface mounting should account for over half the printed circuit sales by the end of the decade—almost four times its present market share. Over the same time span, shipments of surface mount components will grow from 30 billion to 100 billion units.

While several surface mount techniques have been devised, the most widely used method is "solder reflow." This method involves three basic steps: applying a solder paste, placing the components on the pc board, and melting the solder (reflow).



Hewlett-Packard was able to cut the size of its spectrum analyzer board in half by mounting components directly onto the surface of the IC board.

The solder paste, which consists of a resin flux impregnated with small nodules of solder, is applied only where the components are to be mounted. This is accomplished by placing a silkscreen or stencil over the pc board. The paste is tacky enough to hold the components in place until soldering is complete. Of the several reflow techniques available, vapor phase soldering is emerging as the best candidate. It provides more flexibility than either thermal conduction or infrared soldering.

Developed by Western Electric in the early 1970s, vapor phase soldering provides excellent temperature control. First a fluorine compound is heated to its boiling point (419° F). Then the cool pc board is immersed in the boiling vapors, which condense, heating the board and melting the solder. The liquid's singular boiling point ensures precise control of the soldering temperature. Yet vapor phase soldering has its drawbacks. The fluorine compound

costs $600 a gallon and gives off environmentally harmful vapors, so precautions must be taken to prevent evaporation.

The Japanese were the first to capitalize on the many advantages of surface mounting. In the late '70s they began incorporating surface mount resistors and capacitors into a variety of commercial products, from video cameras to portable stereos. In the U.S., military applications got first call because of the keen interest here in improving the reliability of increasingly sophisticated electronic hardware, as well as reducing its size and weight. Rockwell International (Cedar Rapids, Ia.) was one of the earliest U.S. companies to go the surface mount route. By using surface mount techniques in an aircraft transceiver, Rockwell engineers were able to increase board density sixfold. Martin Marietta (Orlando, Fla.) is also using a surface mount approach in the LANTIRN tactical navigation system it is developing for Air Force fighter aircraft. In fact, the company built a $6 million facility to demonstrate the cost-saving and size-reducing potential of this technology.

These successful military applications are now driving commercial manufacturers to take a hard look at this new technology. General Motors, for example, has adopted it for car radios and electronic ignition systems. Kodak has applied the surface mount approach to its disc camera product line. And many other companies, including Xerox, Motorola, and Hewlett-Packard, are turning to surface mounting for various new products.

Electronic components specially designed for surface mounting are now available from dozens of manufacturers. And the number of component types available in surface mount form has mushroomed in the past year, from roughly 5000 to over 18,000. Motorola, Texas Instruments, Signetics, NEC, and National Semiconductor are but a few of the major suppliers now committed to surface mount technology.

The technology is growing so fast, in fact, that manufacturers have an urgent need to standardize components. Packages from the different suppliers are incompatible in many areas. Standardization is particularly crucial for integrated circuits, where at least four different package styles are competing for market share. Competitive pressures will undoubtedly force manufacturers to adopt a common format within the next few years. □

—*Stephen W. Hinch*

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SCIENCE/SCOPE

In designing and making a satellite part entirely via computer, Hughes Aircraft Company developed what may be a first in computer-aided design/computer-aided manufacturing. The part is a launch lock pivot plate for the Intelsat VI communications satellite. (The plate keeps the inner and outer sections of the spacecraft together until it is time to begin the spun/despun operation in space. This operation stabilizes the satellite in orbit.) The plate was designed on a CADAM system and made on a computerized milling machine driven by a ComputerVision system. Because CADAM lacks the ability to run milling machines without extensive manual manipulation, engineers developed a custom translator. This new programming allowed CADAM data to be understood by ComputerVision and, in turn, by the milling machine. The use of CADAM and ComputerVision in tandem is believed to be an industry first.

Heat pictures are screening printed circuit boards for such defects as open or short circuits and failed components. The Automatic Infrared Test & Inspection System (AITIS) uses a cooled, 60-element infrared detector to create a high-resolution thermogram. A computer isolates faults by comparing a tested board with a master thermogram stored in computer memory. Components that appear too warm or too cool are shown in color-coded temperatures on a video monitor. As a complement to automatic test equipment, AITIS saves time and money. Hughes developed AITIS under its independent research and development programs and contracts with the U.S. Army Missile Command and U.S. Air Force.

An advanced military communications satellite network will let U.S. bombers and airborne command posts remain in continuous contact with designated ground and naval stations anywhere in the world. The new MILSTAR network will consist of satellites in various orbits and hundreds of terminals aboard aircraft, ships, submarines, and in ground units and command centers. Hughes is designing survivable, secure, and jam-resistant terminals for B-1 and B-52 bombers, E-3A Airborne Warning and Control System (AWACS) early-warning aircraft, E4 command post aircraft, VC-137 "Air Force 1," and other aircraft involved in the Air Force portion of the joint services network.

Some of the fastest digital integrated circuits yet built have been demonstrated at Hughes. The circuits, made of gallium arsenide, are biphase clock flip-flops configured to perform frequency division. They were operated at frequencies up to 5.77 GHz, the highest division speed yet reported for integrated circuits operating at room temperature. The circuits were fabricated by electron-beam lithography (using a Hughes system) to produce gate lengths of 0.5 micrometers in the MESFET switching transistors. These gallium arsenide devices could be used in very-high-frequency signal processing or as interfaces to more complex chips, including Very High Speed Integrated Circuits.

Career growth opportunities exist at Hughes Support Systems for a variety of engineers qualified by degree or extensive work experience. They include systems engineers, radar engineers, and software and hardware design engineers for major simulation and test equipment programs. Also, field engineering posts throughout the U.S. offer travel, autonomy, and responsibility for the life cycle of Hughes electronics systems. Please send your resume to Lowell Anderson, Professional Employment, Dept. S2, Hughes Aircraft Company, P.O. Box 9399, Long Beach, CA 90801-0463. Equal opportunity employer. U.S. citizenship required.

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IN-OFFICE DIAGNOSTICS SET FOR GROWTH

Start-ups endure short-term losses for future gains

The investment community is now shying away from medical-equipment stocks as a result of a downturn in spending in the health-care industry. Pressure from consumers, insurers, and the federal government is forcing the industry to be more discriminating in its capital-equipment purchases as a means of containing skyrocketing medical costs.

The market is expected to pick up again, however, as the medical community looks for tools that increase the efficiency of health-care delivery. While medical service and equipment costs now represent 10.5% of the gross national product, they are projected to account for 12.3% by 1990.

Among the medical-equipment suppliers positioned for growth are makers of inexpensive diagnostic tools that analyze blood and urine chemistries or monitor organ functions in the physician's office. Priced from $5000 to $15,000, these devices could play integral roles in helping the health-care industry speed diagnoses while reducing spending.

The bulk of chemical testing is now performed by hospitals on machines costing as much as $500,000. Hospital labs charge physicians $4 to $6 for each test and take as long as a week to process and return results. Emerging in-office analyzers, however, provide immediate results at a cost of about 40¢ per test.

Most of the companies supplying diagnostic systems for doctors are still in the start-up stage and consequently show depressed or flat earnings. But these earnings should improve over the next two years, once capital spending within the medical arena resumes. While in-office systems now represent a negligible share of today's $2 billion diagnostic market, they could account for as much as 10% of the $4 billion market projected for 1990.

by George J. Stasen

Three companies whose product lines best exemplify the technologies available for in-office diagnosis are Electro-Nucleonics, Genetic Systems, and OCG Technology.

Electro-Nucleonics (Fairfield, N.J.; OTC) unveiled its Gemstar blood-analysis machine in mid-1982. Priced at $12,000, the device allows physicians to perform 21 preprogrammed tests that check for diseases ranging from diabetes to gout. A 12-test profile can be performed in 16 minutes by a doctor or nurse who has had little or no training. Since Electro-Nucleonics first introduced Gemstar, more than 1000 units have been installed.

The company also offers two clinical chemistry systems that are marketed to medium-sized hospitals and commercial laboratories. Complementing Electro-Nucleonics' blood-analyzer sales is its captive consumable reagents business, which has been growing at a 40% average annual rate and now accounts for over half of total revenues.

The diagnostic equipment market is expected to pick up as the medical community looks for tools that increase the efficiency of health-care delivery.

In fiscal '83, ended June 30, Electro-Nucleonics posted a net income of 53¢ a share on revenues of $43 million. The company expects to show earnings of 25¢ a share on revenues of $50 million in fiscal '84. Electro-Nucleonics attributes the decline in earnings to mechanical problems associated with its latest mid-size clinical analyzer. The company's earnings estimates for fiscal '85 are more buoyant, however: 55¢ a share on revenues of $60 million.

Genetic Systems (Seattle; OTC), a bioengineering supplier, is working in joint ventures with such instrumentation firms as Syntex (Palo Alto, Cal.) and Applied Biosystems (Foster City, Cal.) to develop diagnostic tools based on DNA probes and monoclonal antibodies. With Syntex the company plans to offer a device that tests for breast, lung, prostate, and colon cancers as well as leukemia. Both Genetic Systems and Applied Biosystems have patents pending on a system that identifies bacterial and viral infections and chronic illnesses.

Now losing money, Genetic Systems is supporting its product development efforts through contract research. For the year ended December 31, '83, the company garnered contract revenues of $3.9 million and interest income of $2.5 million but showed a net loss of 8¢ per share. In '84, Genetic Systems should show a net loss of 7¢ per share on contract revenues of $6 million and interest income of $2.8 million. The company expects to pass the break-even point in '85.

OCG Technology (New York; OTC) is offering an $11,500 instrument that enhances the diagnostic capabilities of electrocardiograms and that is intended for use by primary physicians for preliminary screening applications. While EKGs are effective in diagnosing heart ailments in patients undergoing physical stress—running on a treadmill, for example—the devices have a 50% failure rate in detecting problems in patients at rest. OCG's Cardiointegraph processes EKG signals from relaxed patients in such a way that differences between healthy and abnormal heart function can be better determined.

At the end of fiscal '83 (June 30), OCG showed a net loss of 12¢ per share on revenues of $900,000. In '84, the company should post a loss of about 14¢ per share on revenues of $2 million. Looking ahead to '85, OCG projects revenues of $7 million and earnings per share of 55¢ to 70¢. □

George J. Stasen is chairman of the board of the investment consulting firm Medical Technology Fund (Flourtown, Pa.).

Price cuts rock PC market

By slashing the prices of its PC line by 18–23% in June, IBM confirmed suspicions along Wall Street that growth within the home/personal computer market is slowing. Analysts claim that IBM cut prices not only because sales of its PCjr were below expectations but also because the company's production capacity had caught up with demand.

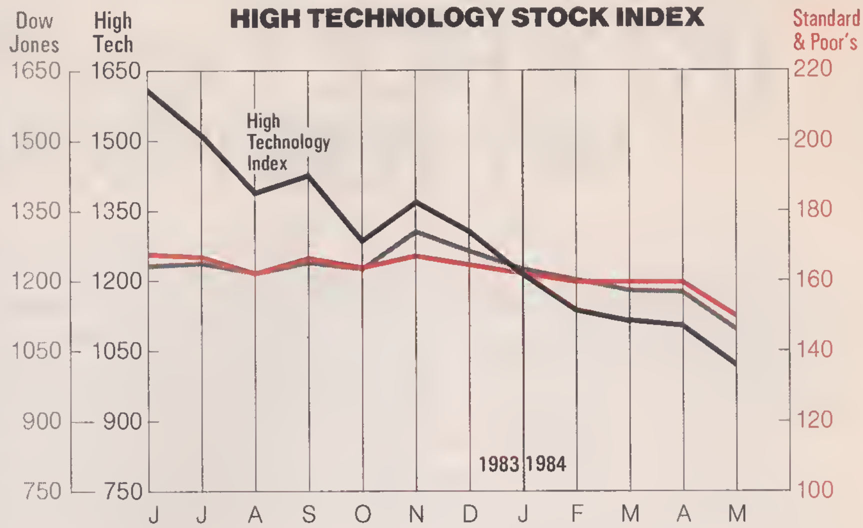
During the first six months of '84, major declines had been seen within the High Technology Stock Index among such personal computer suppliers as Coleco (32 to 14½), Commodore (41 to 14), and Tandy (43 to 27). The IBM move, however, raised concern about the earnings capabilities of other vendors, including Eagle, Columbia Data Systems, KayPro, and Compaq. To remain competitive in the market, these makers of IBM-compatible machines are being forced to cut prices, as well as profit margins, on their products. While lower margins will not dent IBM's earnings, they could have a big effect on smaller suppliers.

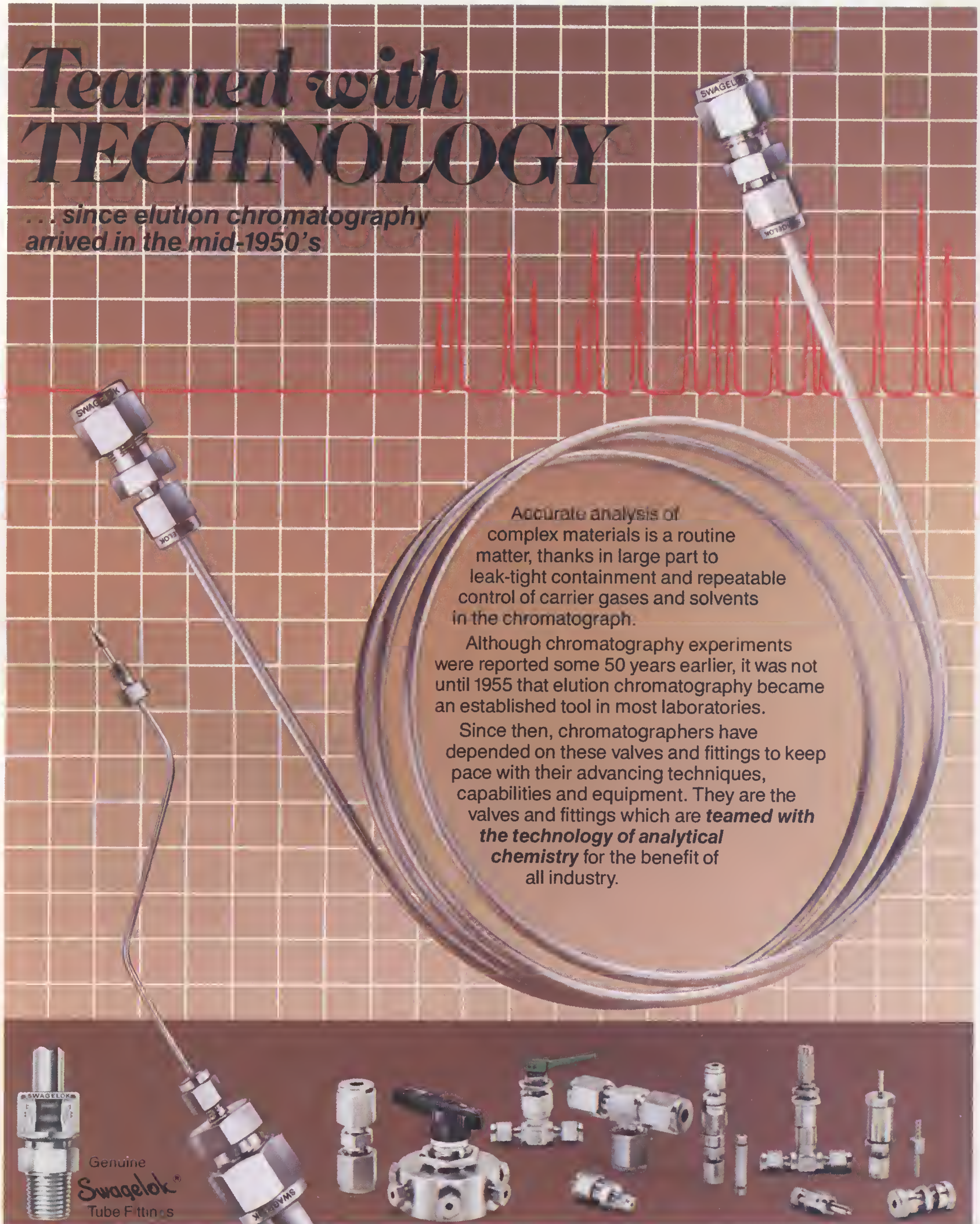
The price/earnings ratios (P/Es) of most high technology stocks were more than 50% lower in May than when the market peaked a year earlier. The reasons for the downturn have been detailed ad nauseum: the huge federal deficit, rising interest rates, and inflation. But in the spring a new factor arose: One of the nation's 10 largest financial institutions—Continental Illinois—announced it was having trouble honoring its debts. Although the Federal Deposit Insurance Corporation stepped in with assistance, the situation put the stability of other banks into question.

The High Technology Index fell a precipitous 8% in May, from 1105.9 to 1017.9. The Dow Jones Industrials fell 5.7%; the S&P 500, 6%.

Among the worst individual performers during the month were telecommunications supplier Tie Communications (17 to 12), office automation supplier Lee Data (13 to 9), and test equipment supplier Sun Electric (13 to 9). One of the largest gains was logged by computer services supplier EDS (27 to 35), which began negotiating with General Motors for a possible acquisition or joint venture.

The High Technology Stock Index was developed by Bud Anderson, editor and publisher of *High Technology Growth Stocks*, a monthly investment newsletter (402 Border Rd., Concord, MA 01742). A list of companies in the index is available upon request. □

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